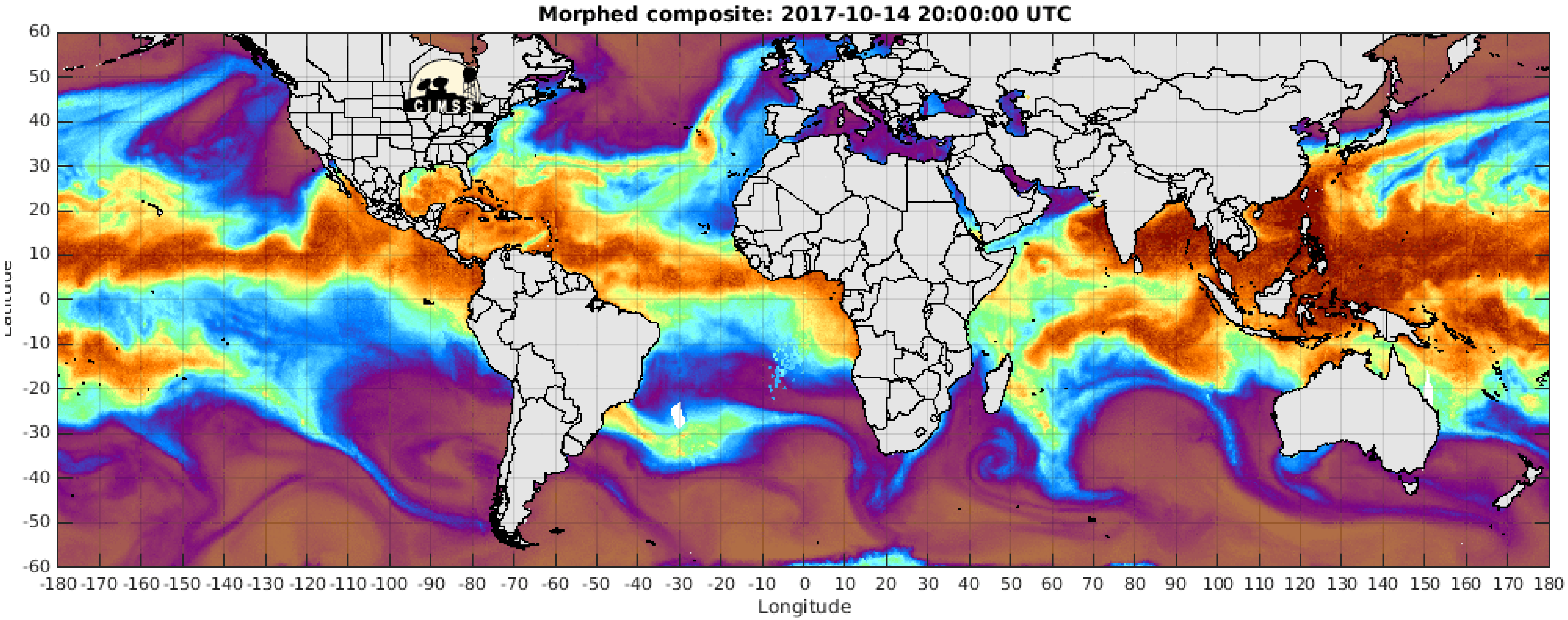
Numerical Water Tracers:

A technique for better understanding the atmospheric water and energy cycle


Morphed composite: 2017-10-14 20:00:00 UTC
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Latitude
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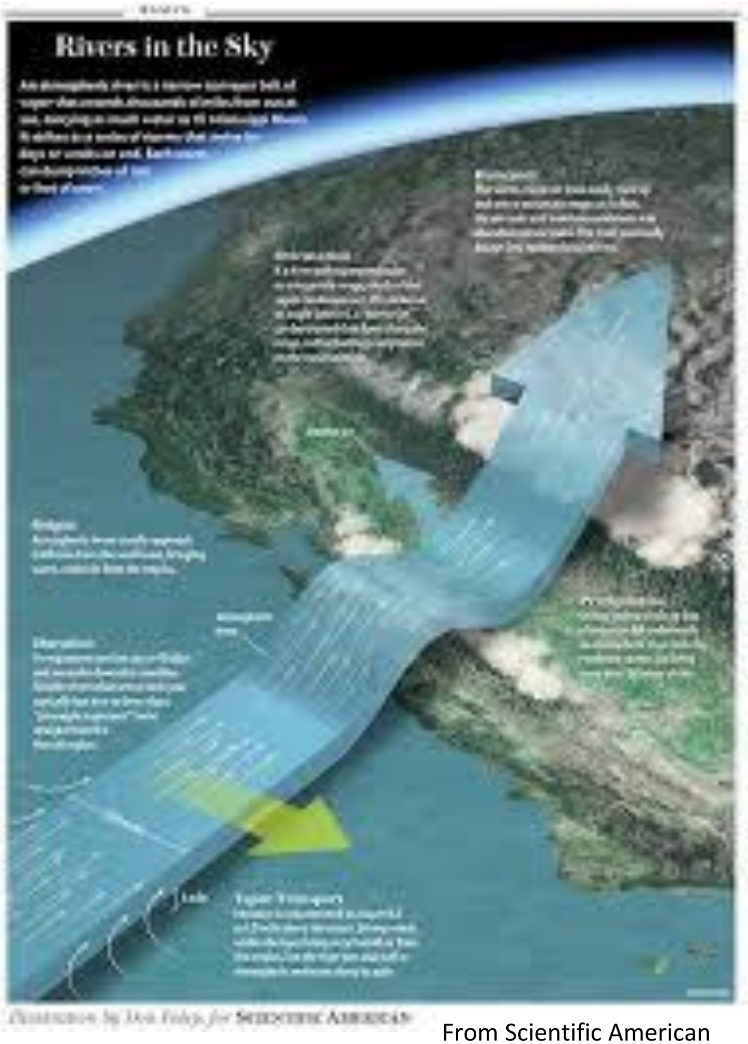
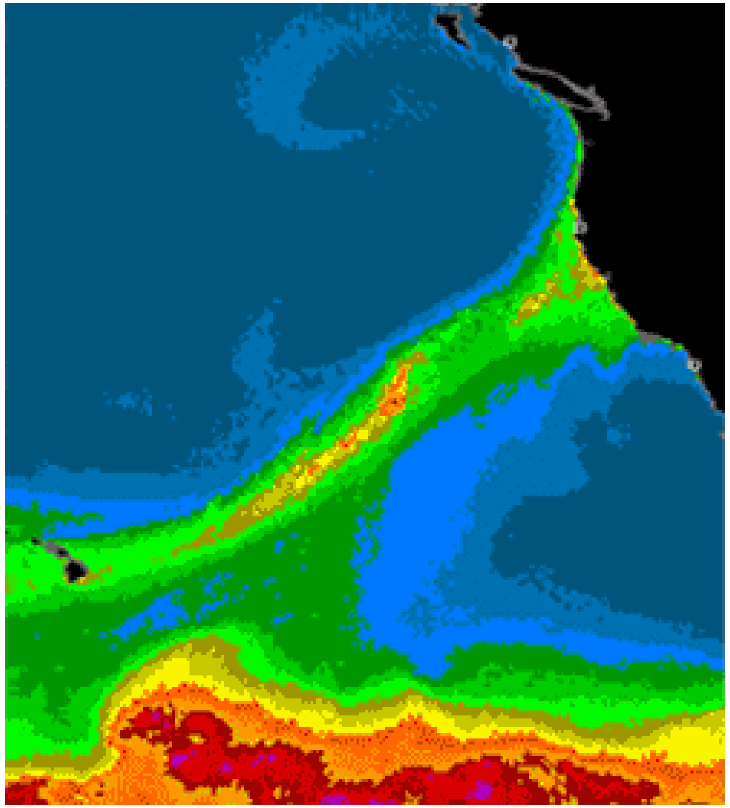
Longitude

Atmospheric Rivers (ARs)



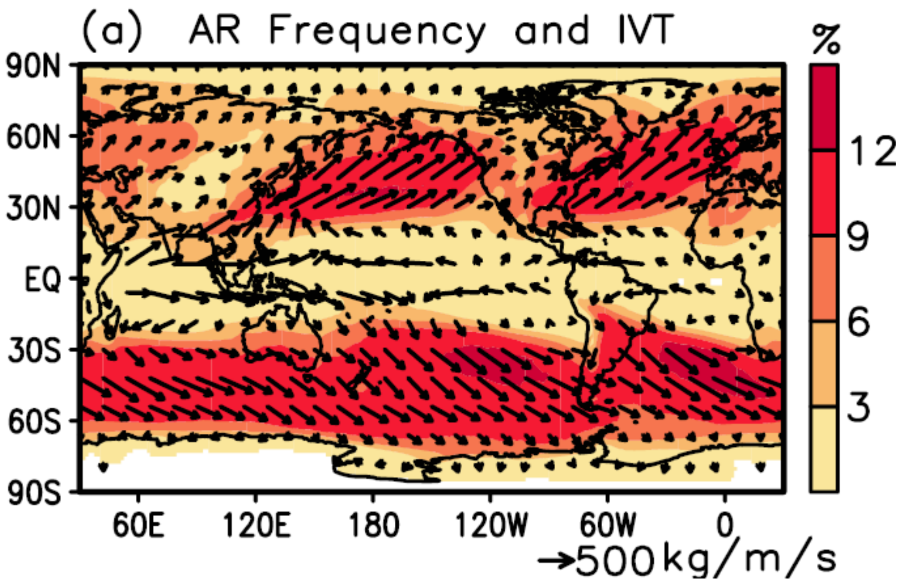
From Scientific American



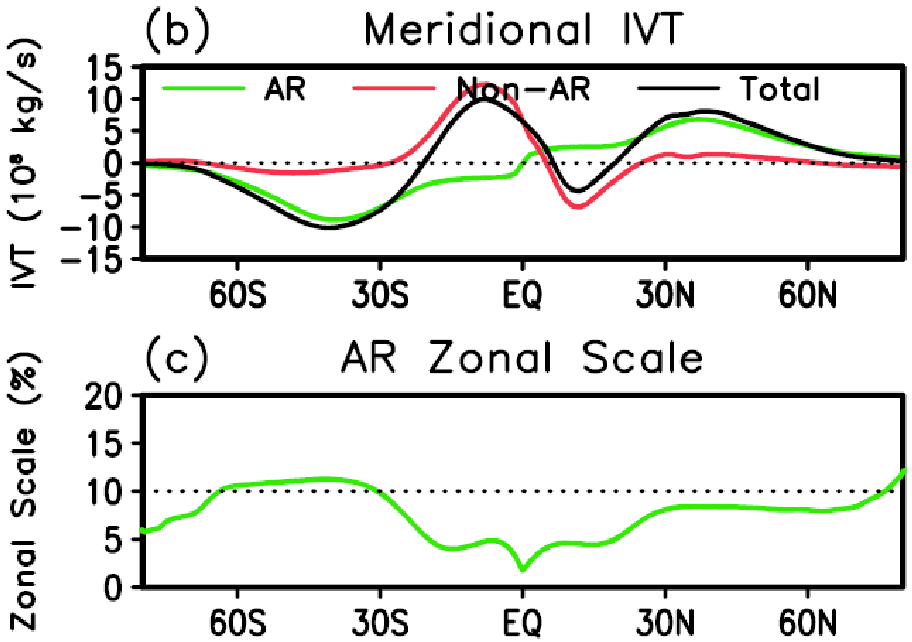
From NOAA ESRL

In the US West Coast, a major driver of extreme precipitation, and even average precipitation in general, is the “atmosphere river”, a plume of elevated integrated water vapor flux.

Atmospheric Rivers



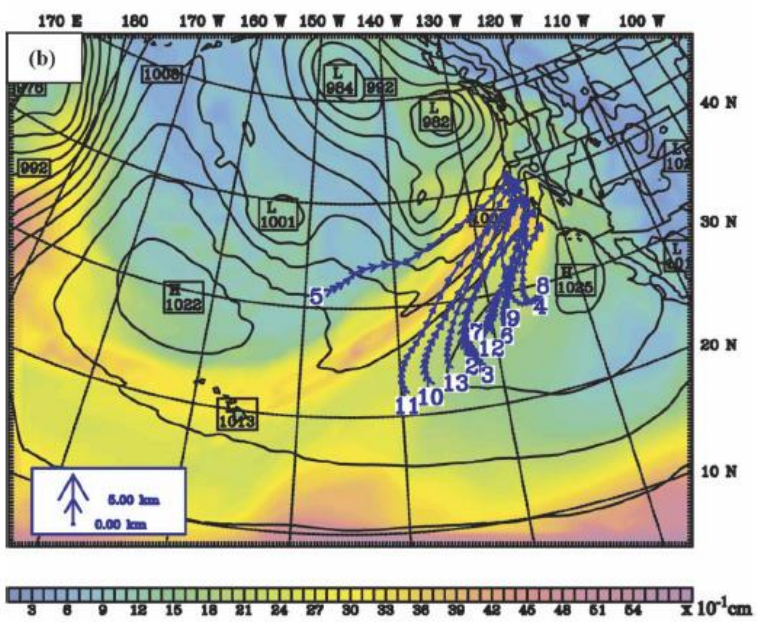
Atmospheric rivers are dominant in the midlatitude storm track regions, and tend to transport moisture westward and poleward.



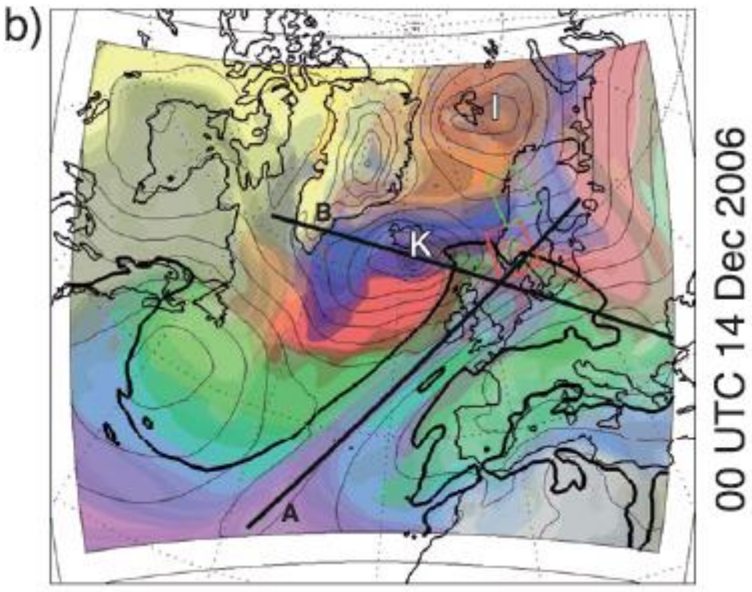
Atmospheric rivers end up producing the majority (~90%) of poleward moisture transport in the midlatitudes, even though they only represent about 10% of the zonal width.

Figures from Guan and Waliser, 2015

It is unknown where ARs get their moisture



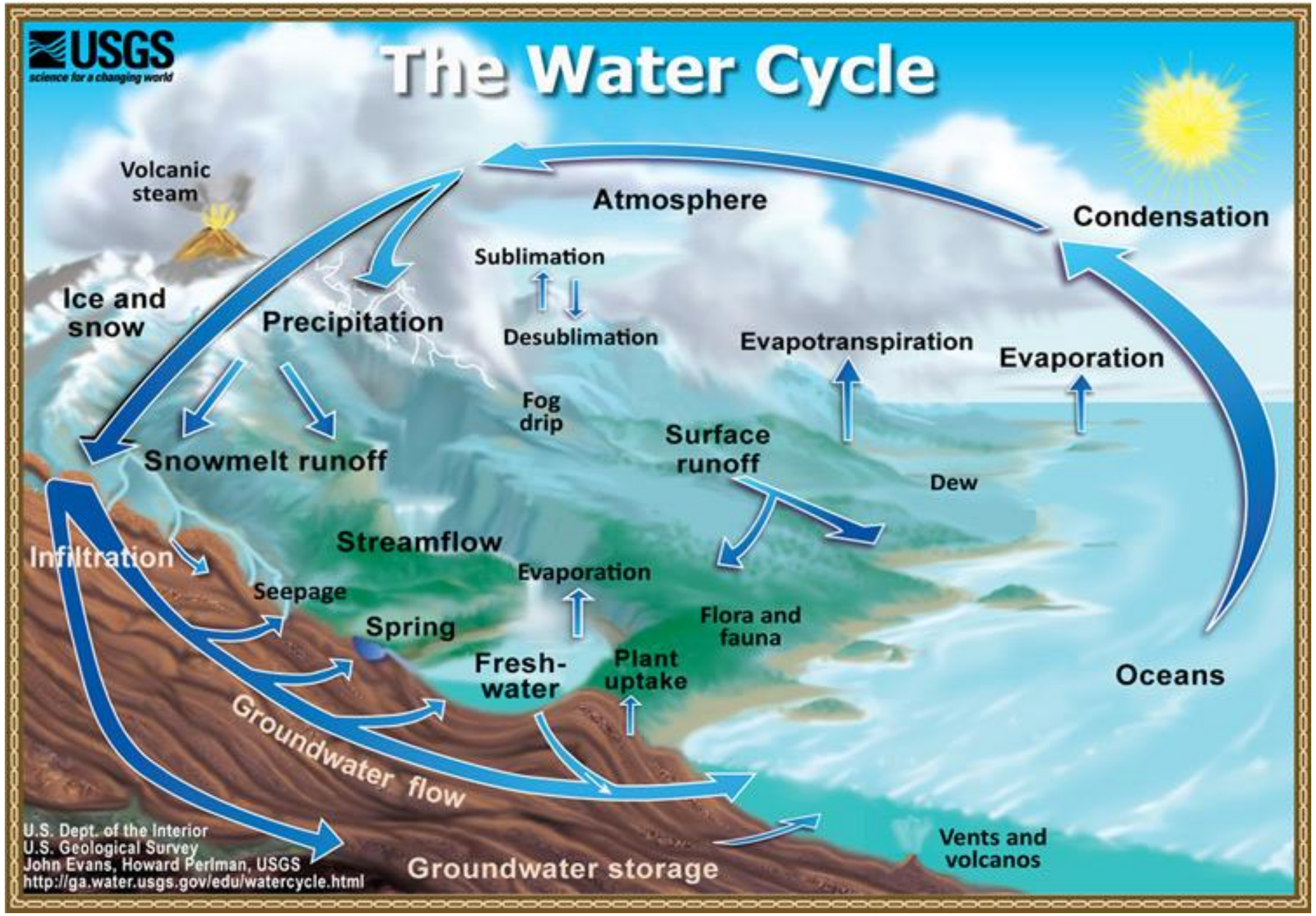
From Bao et. al. 2006



From Sodemann and Stohl, 2013

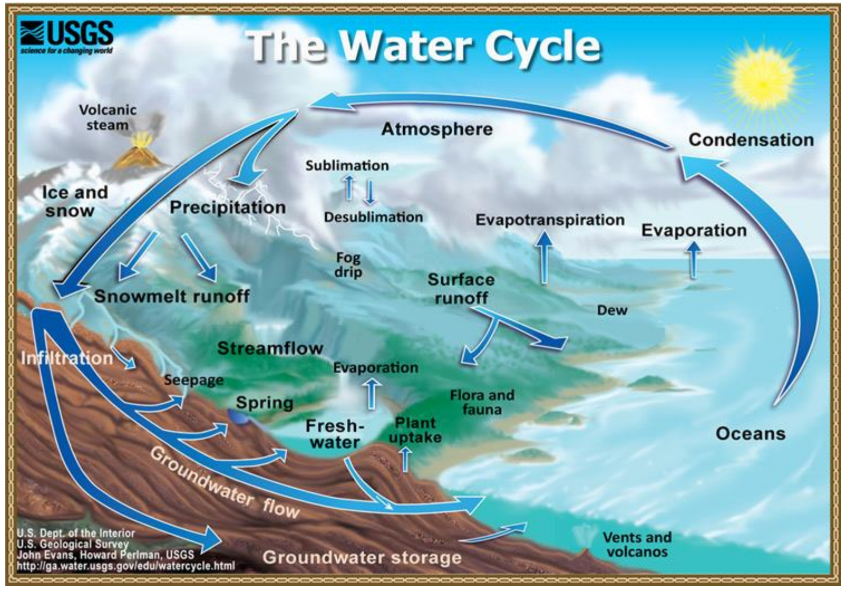
Some case studies have shown that locally-evaporated moisture is dominate, while others have shown a significant amount of tropical moisture (indicating long-distance moisture transport).

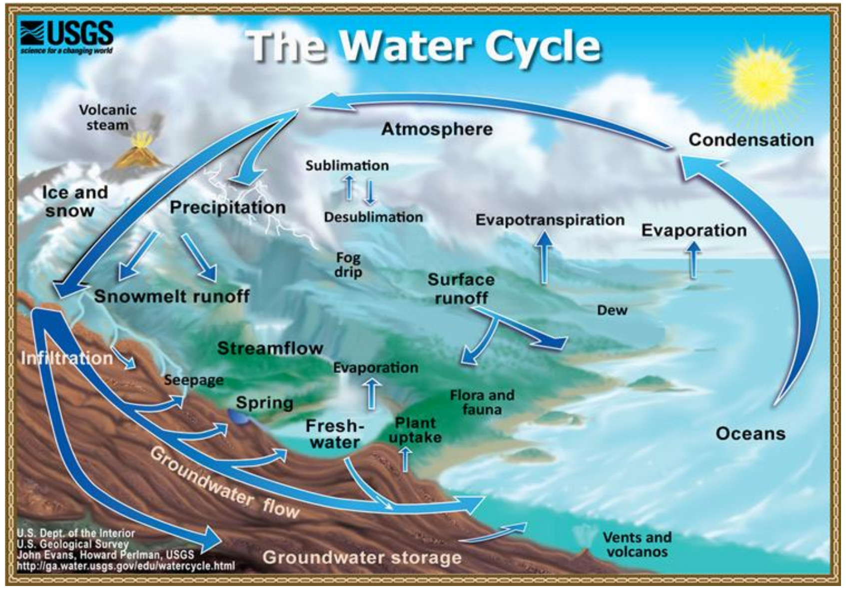
Global Climate Models



The water cycle is simulated in climate models, which gives us the opportunity to examine and constrain the related fluxes and reservoirs, at least as simulated by the model.

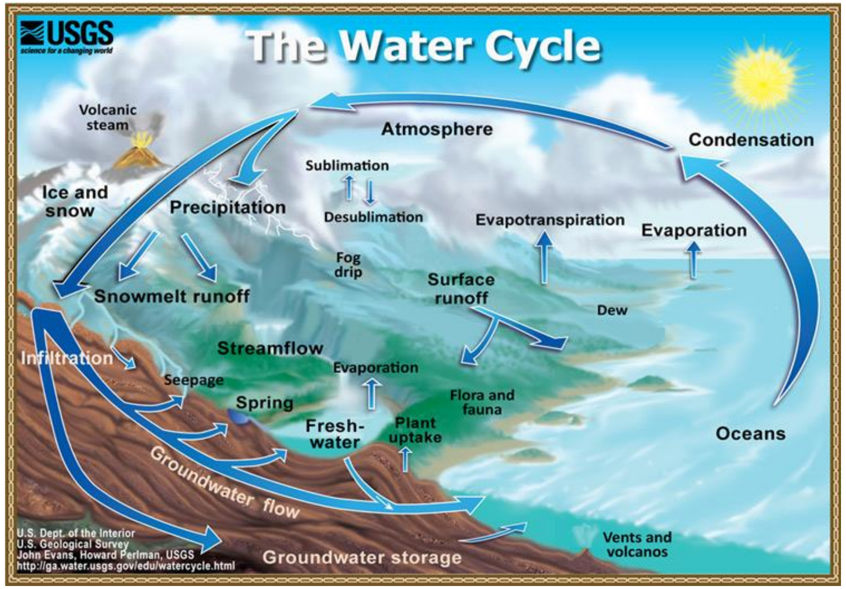
Water tracers

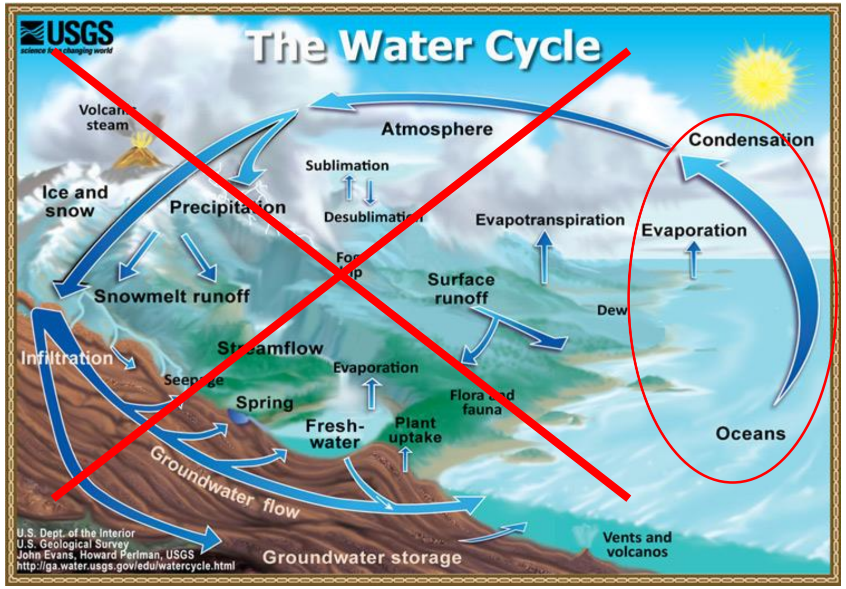




One can construct a secondary hydrologic "tracer" cycle in the model, that goes through all the same processes as the original, but has no influence on any other aspect of the earth system (no radiative effects, latent heating, wet deposition, etc.).

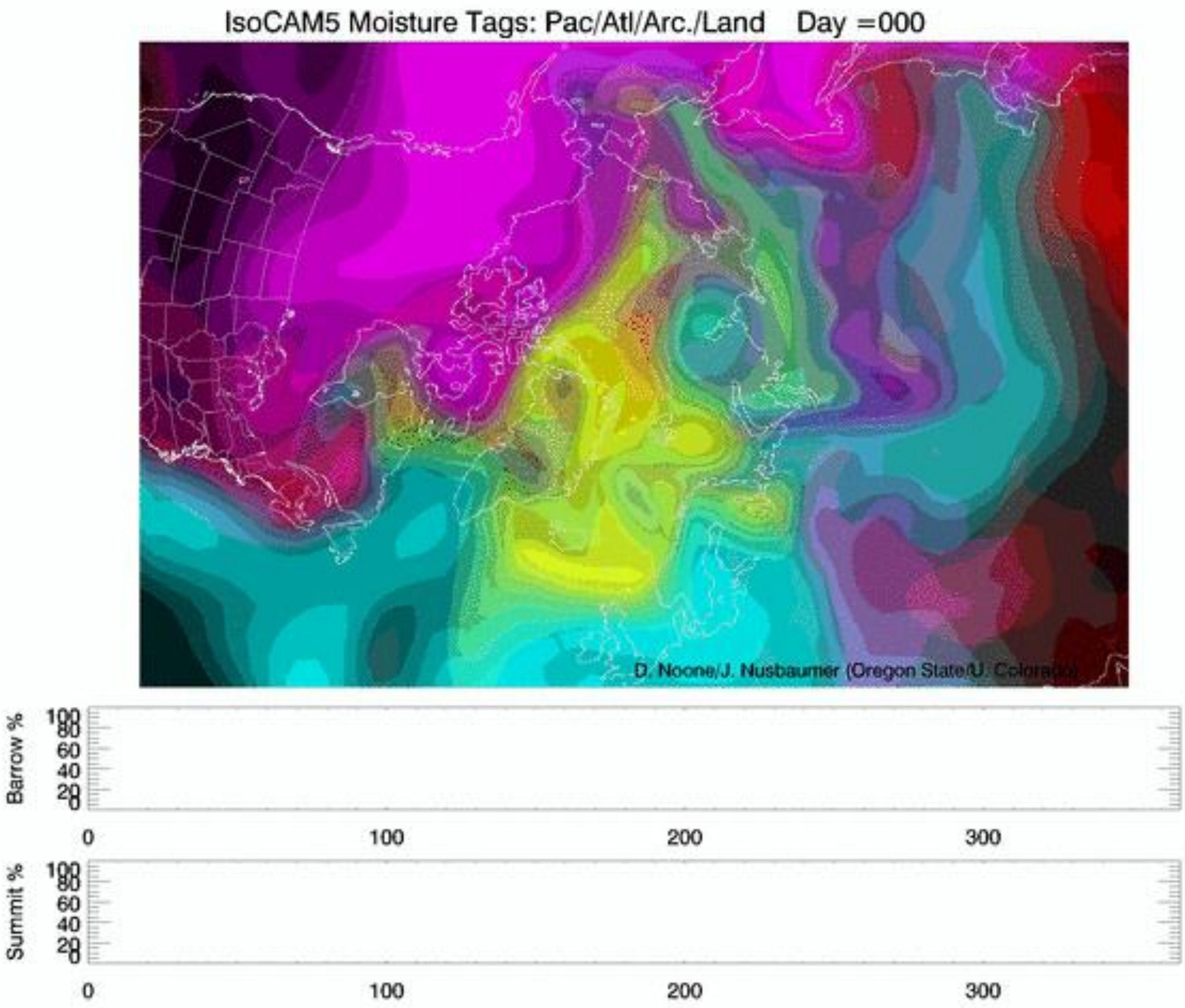
Water tracers



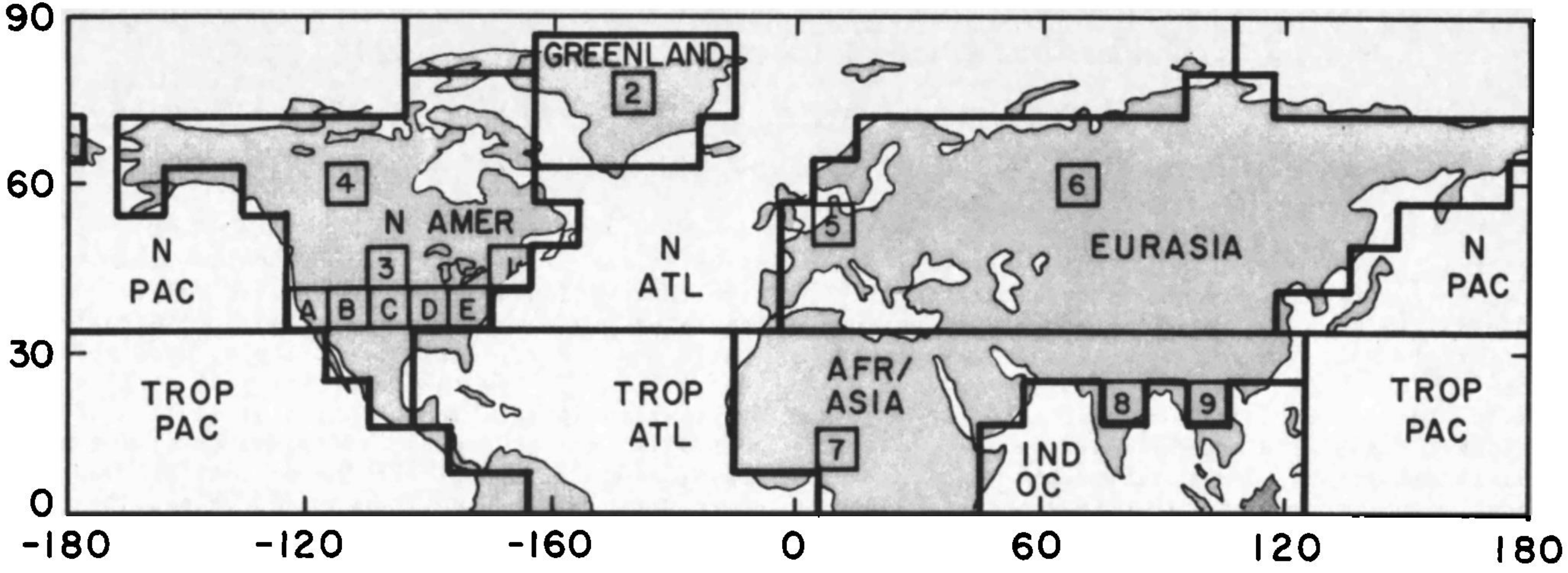


One can then construct water tracers or “water tags”, that represent only one aspect of this secondary hydrologic cycle, allowing for one to determine the impact of specific fluxes, sources, and sinks.

Water tracers



Water Tracers



From Koster et al., 1986

Vapor Source Distribution (VSD) tracers

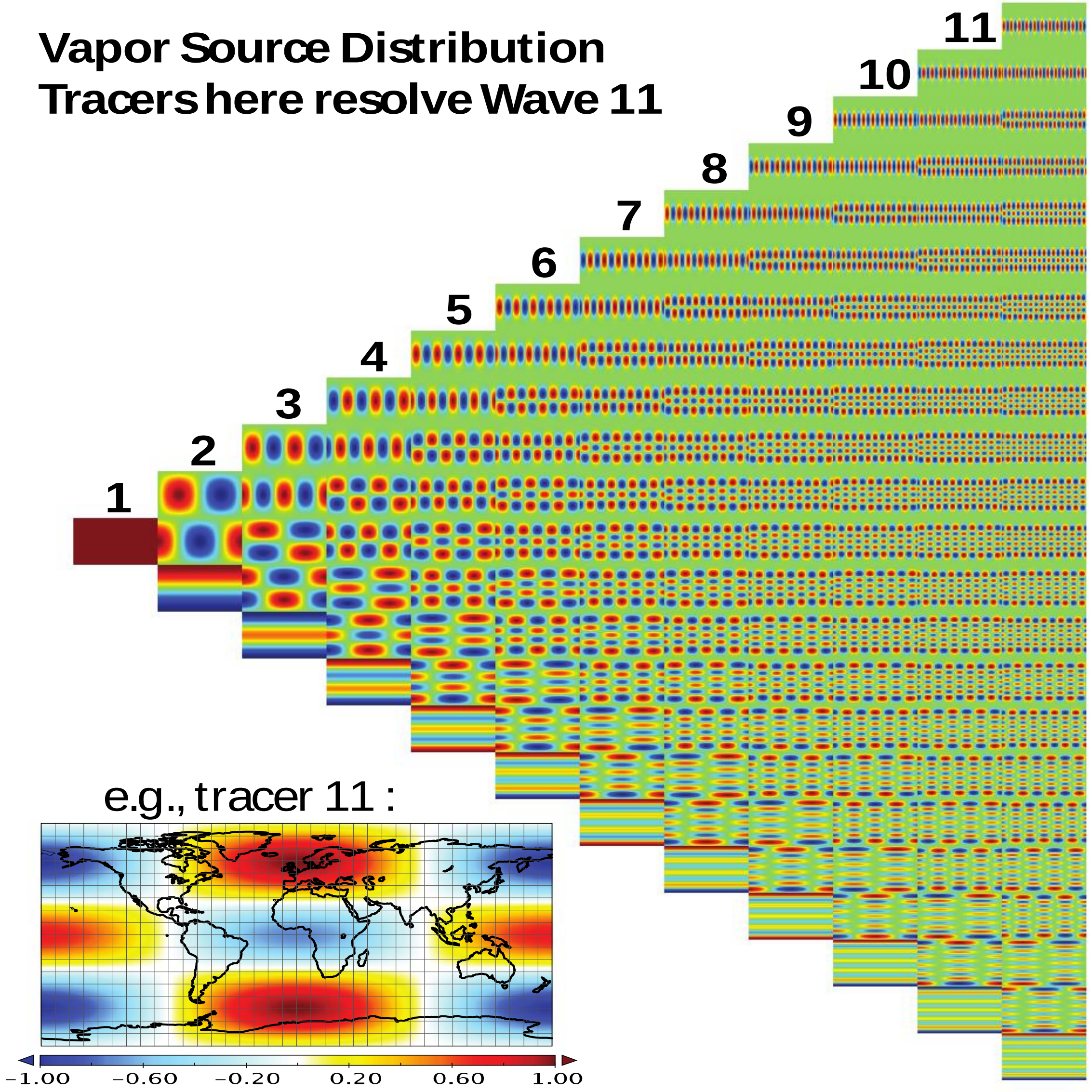
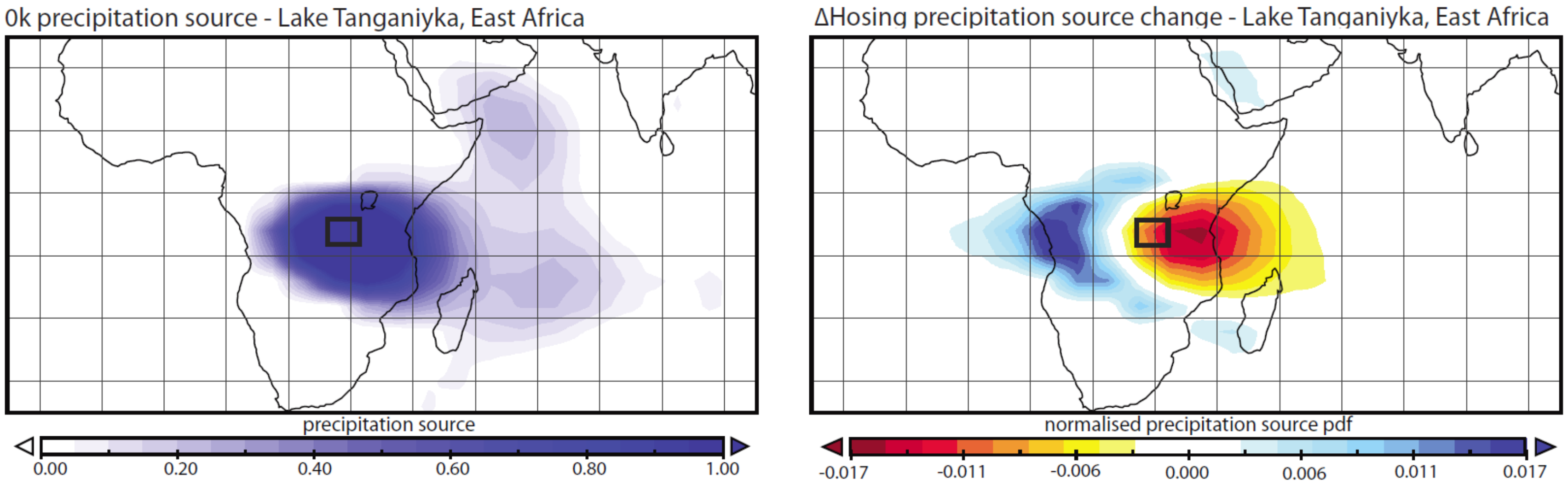


Figure from Allegra LeGrande

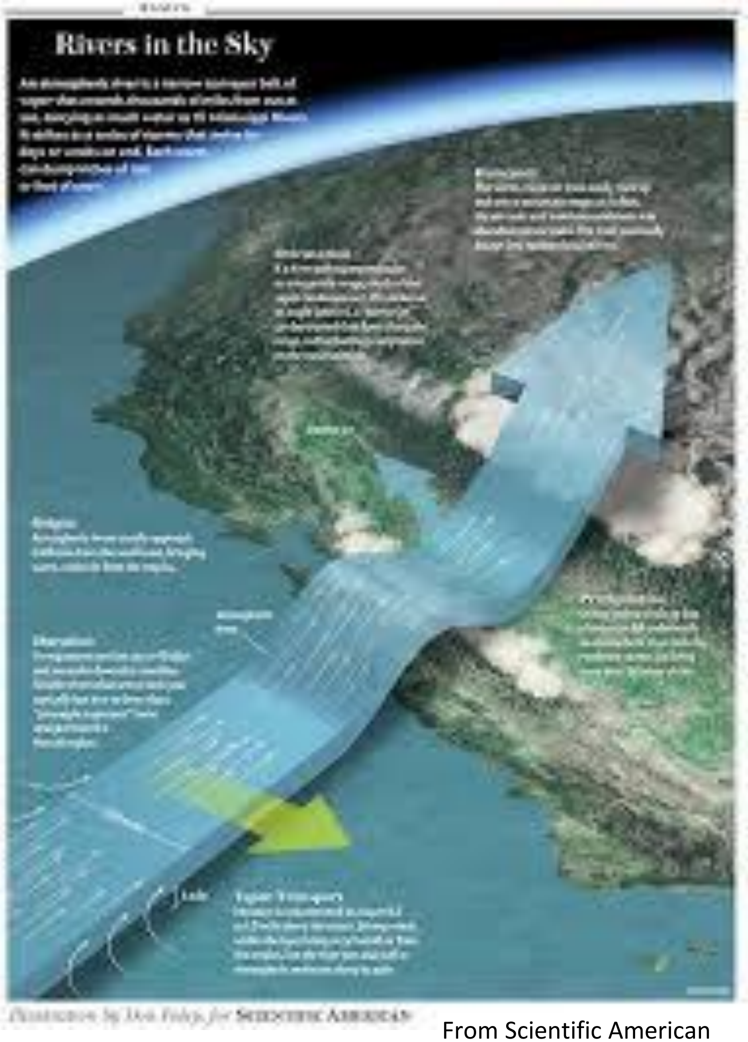
Precipitation source changes



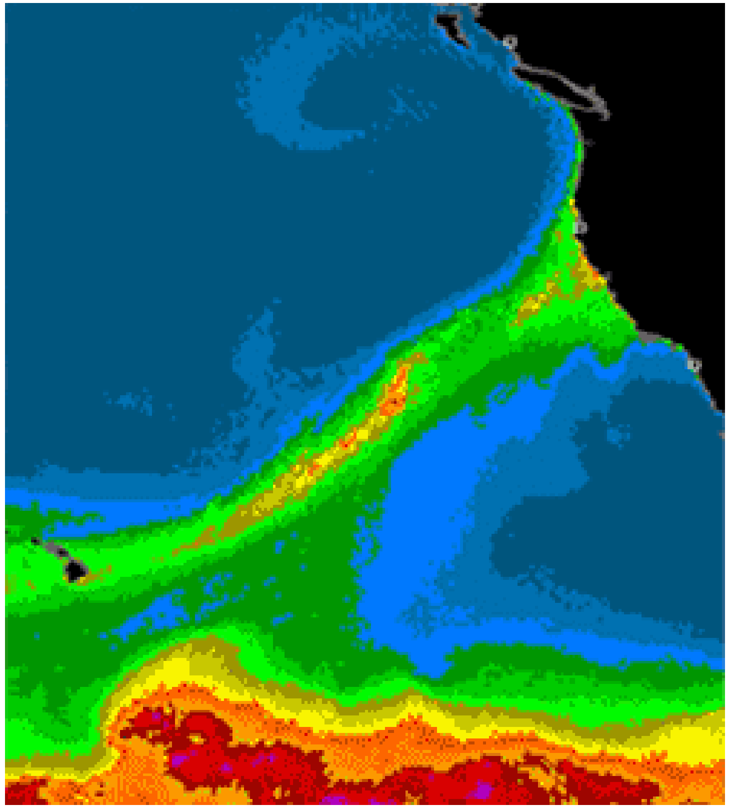
From Lewis et al., 2010

Changes in moisture source can produce significant changes in the isotope values at a particular location, by, for example, shortening the mean transport distance, and thus reducing the amount of Rayleigh distillation that occurs.

Atmospheric Rivers (ARs)



From Scientific American



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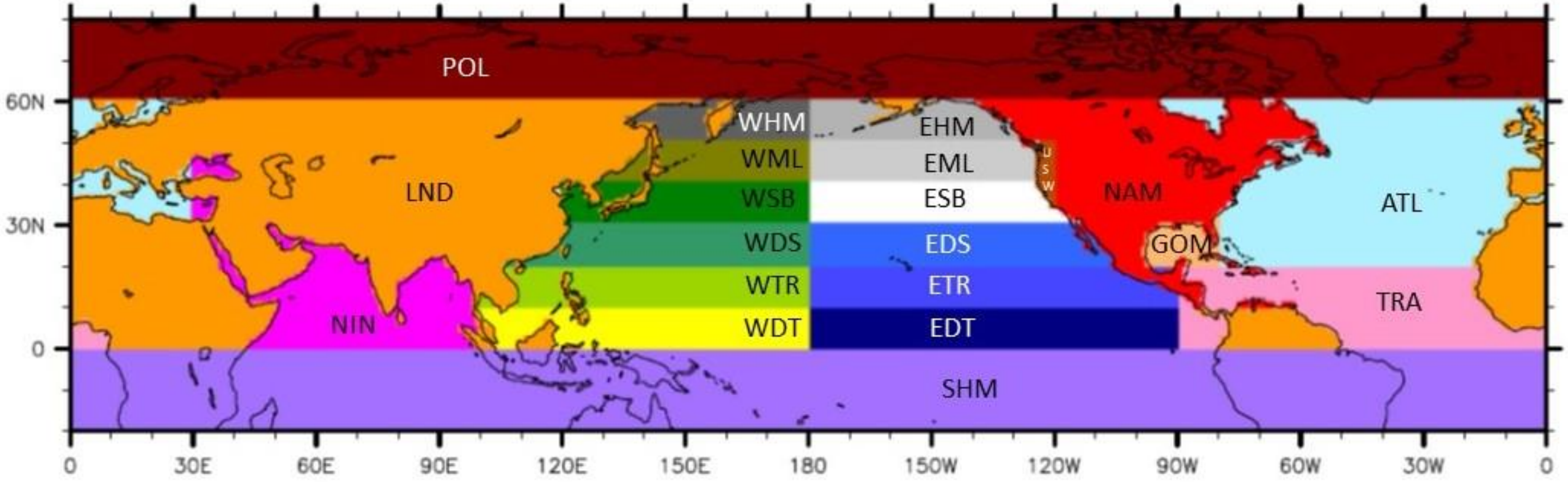
In the US West Coast, a major driver of extreme precipitation, and even average precipitation in general, is the “atmosphere river”, a plume of elevated integrated water vapor flux.

Water tag experimental setup



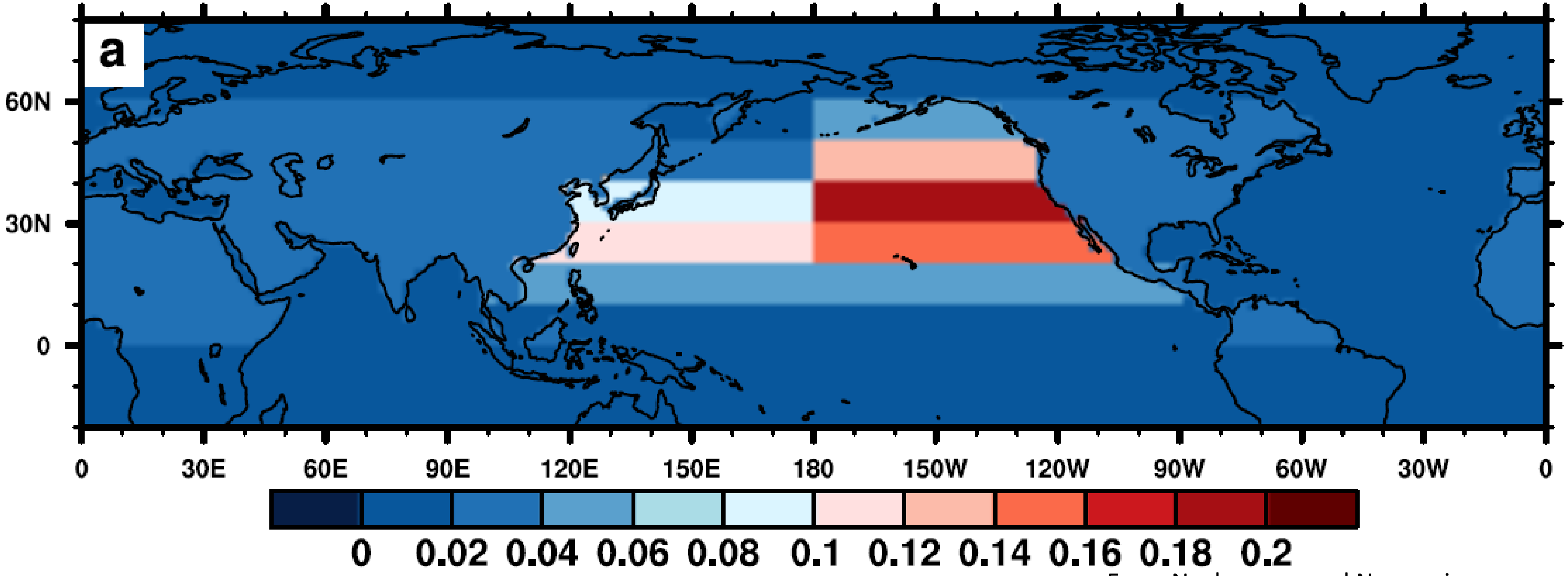
From Nusbaumer and Noone, in prep

$$R_i = \frac{q_i}{q}$$

$$q = \sum_{i=1}^{21} R_i q_i$$

The planet is divided into "tag regions", where a single water tracer, or tag, represents all of the surface evaporation/sublimation from that region.

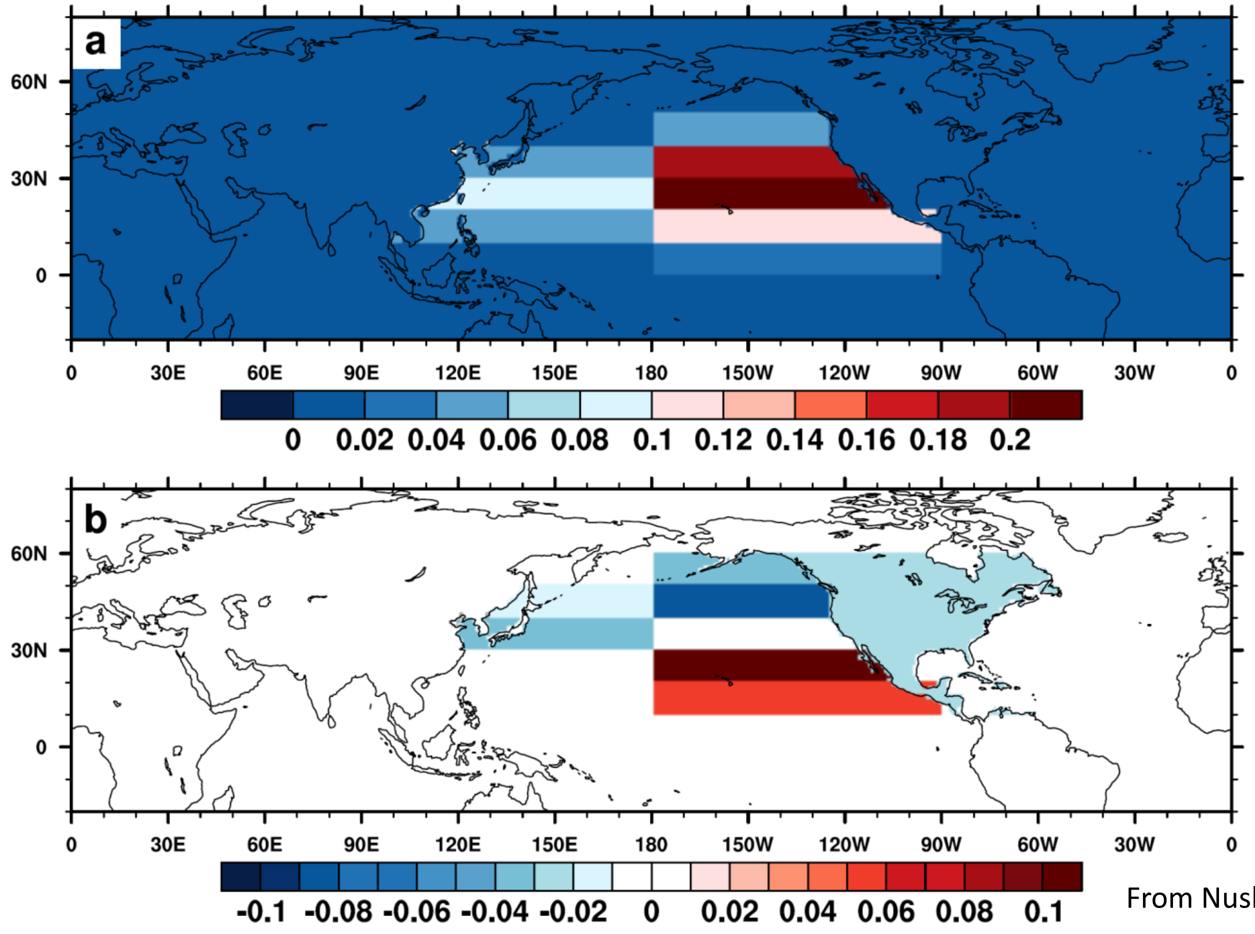
Climatological Moisture sources (DJF)



From Nusbaumer and Noone, in prep

For DJF, the climatological, time-averaged moisture source for the West Coast of the United States is pre-dominantly the Northeast Pacific subtropics and lower midlatitudes.

AR Moisture sources



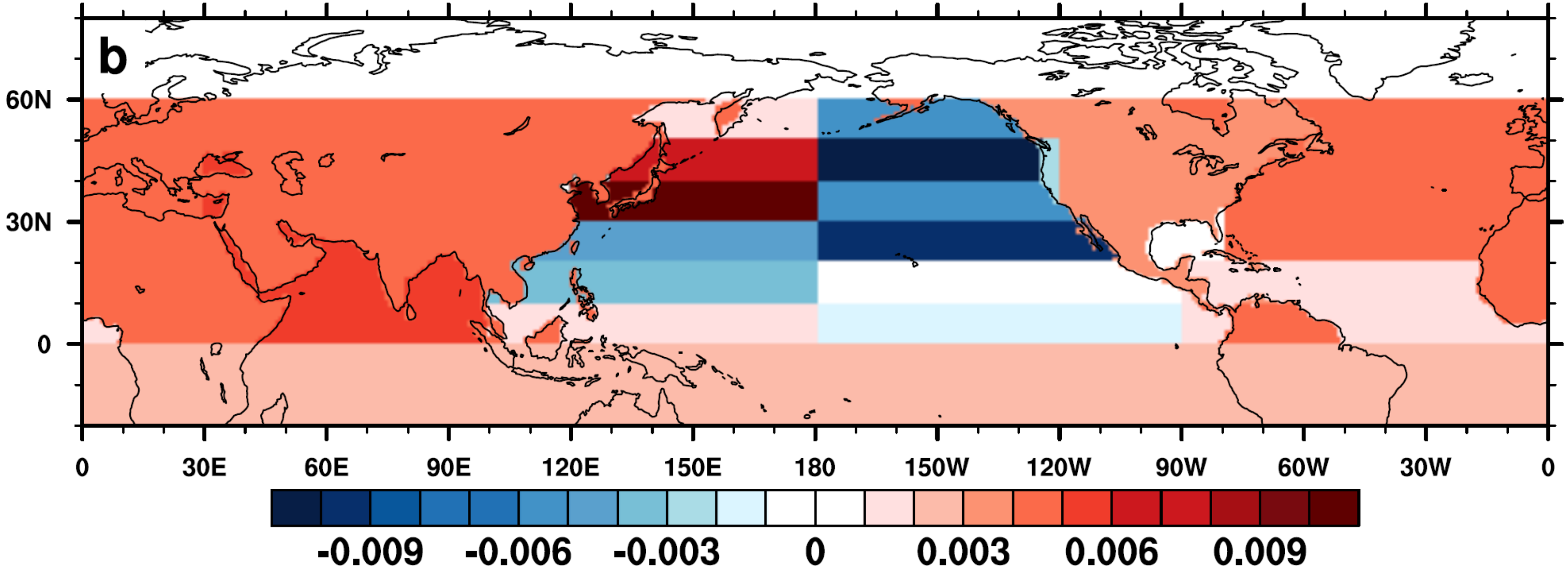
Average moisture source for Atmospheric Rivers

Difference between AR moisture source and climatological (time-average) moisture source

From Nusbaumer and Noone, in prep

Most of the moisture from Atmospheric Rivers comes from relatively local sources, but there is a significant increase in the amount of tropical moisture in ARs relative to the climatological mean.

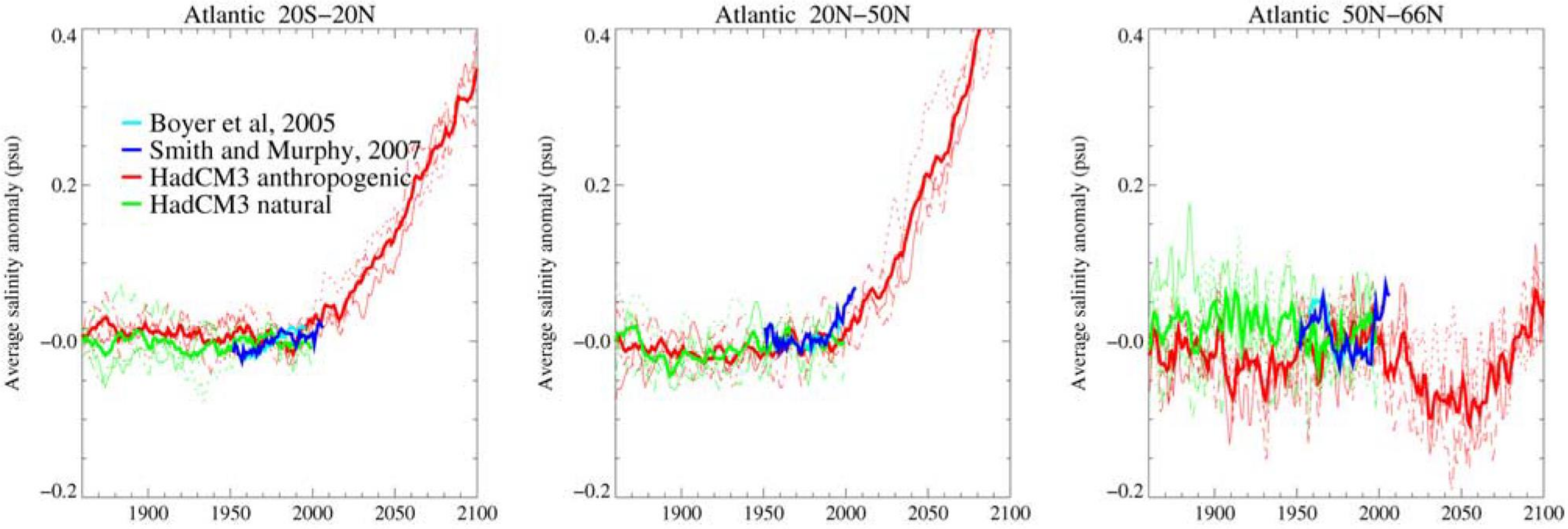
AR Moisture source changes due to global warming



From Nusbaumer and Noone, in prep

In the future, the fraction of moisture from local sources decreases, while the fraction of moisture from remote sources increases. This appears to be an almost universal response, not just a US West Coast response, or a response for just Atmospheric Rivers.

Atlantic Salinity



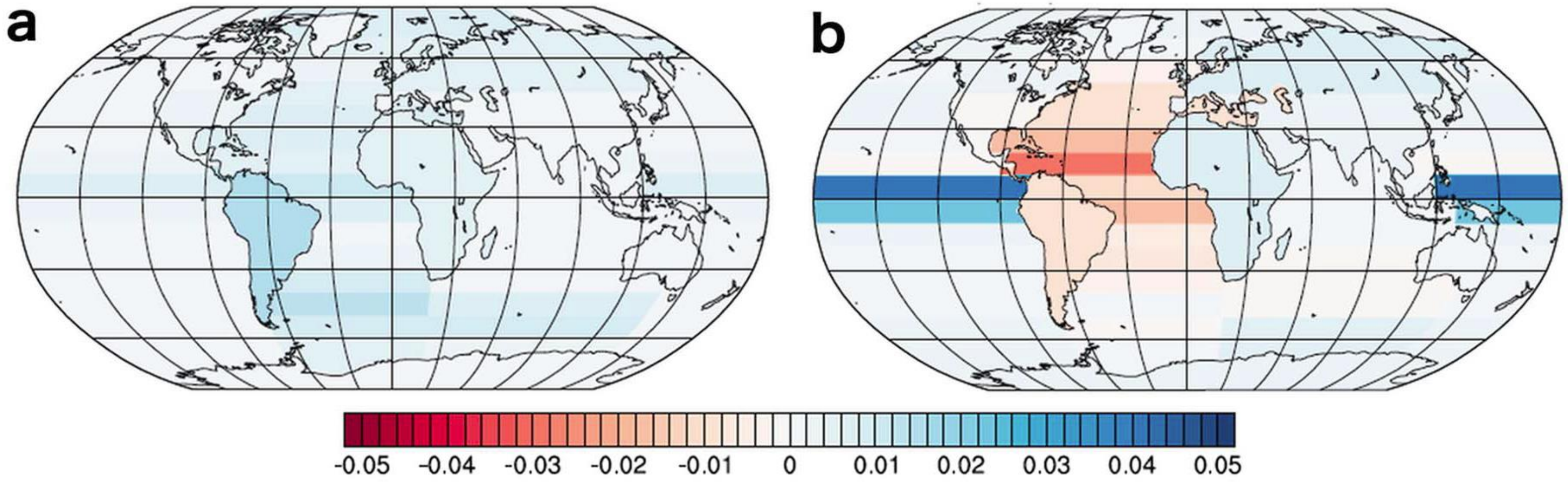
From Stott et al., 2008

The Atlantic Basin has been getting saltier, and is projected to increase in salinity over the 21st century. The salinity changes are driven by changes in the Atlantic freshwater budget, but what is driving those changes?

Atlantic Salinity

Change in local precip due to changes in evaporation

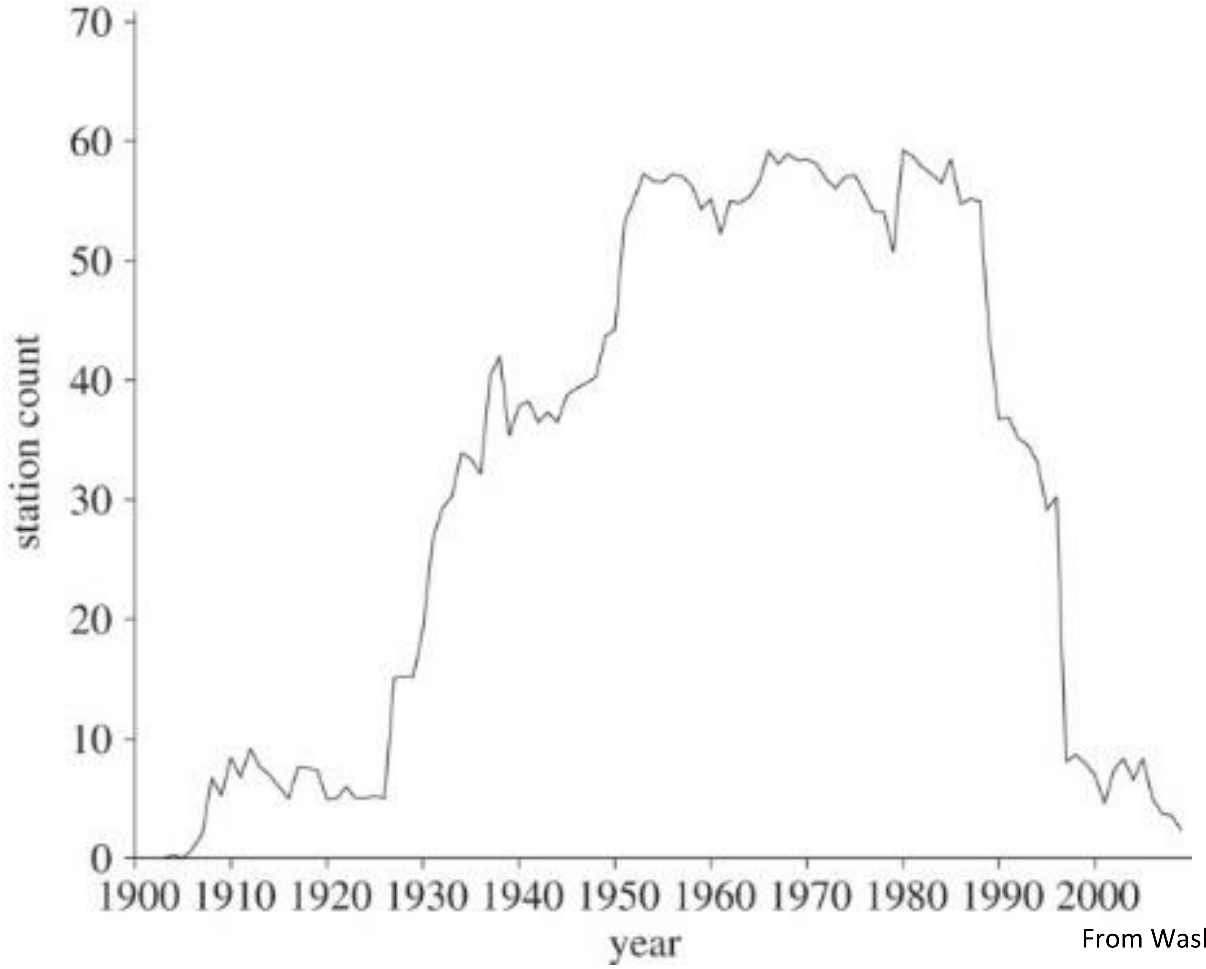
Change in local precip due to changes in moisture transport



From Singh et al., 2016

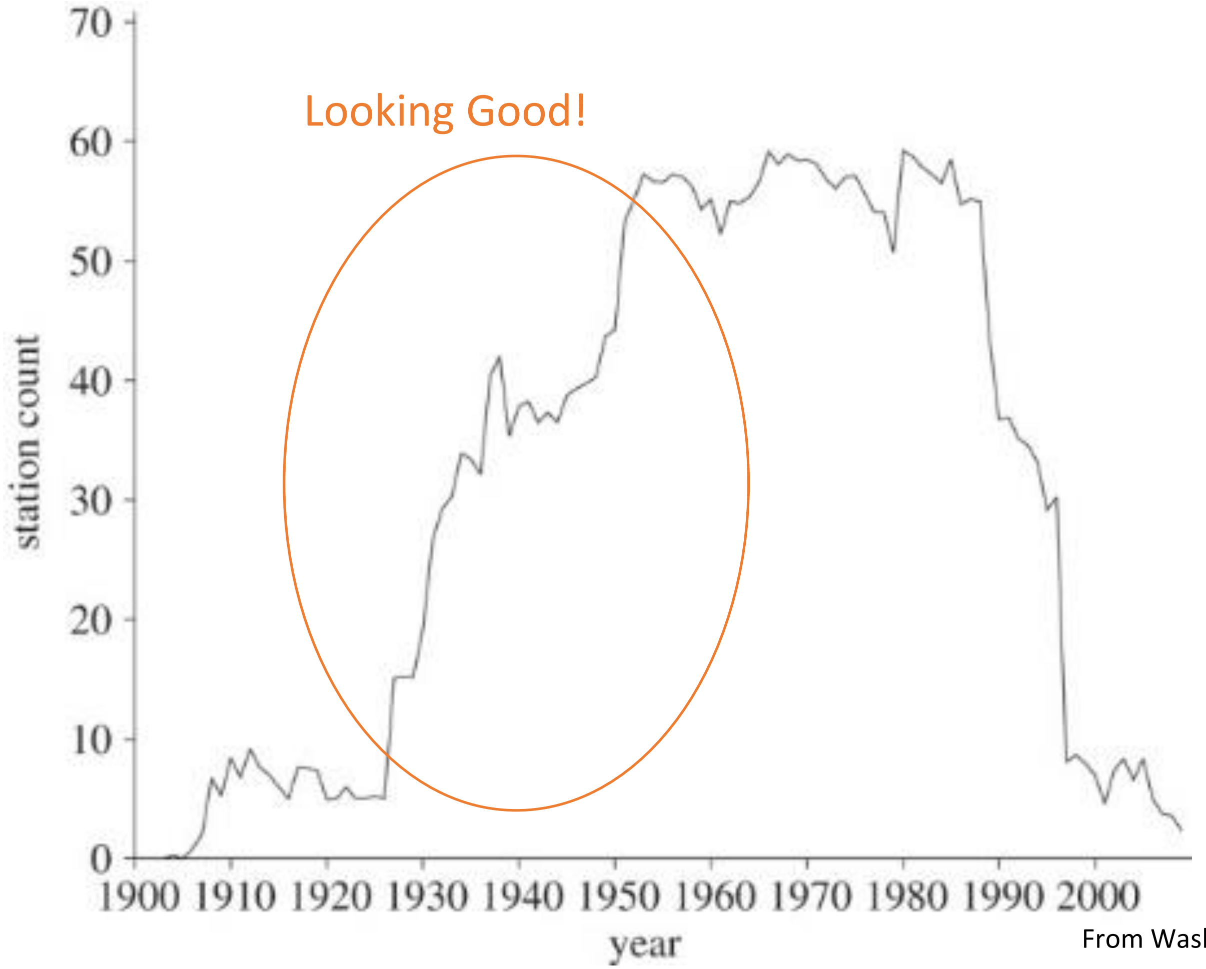
Water tracers in CAM5 have been used to demonstrate that the increases in Atlantic basin salinity in global warming simulations may be driven by changes in atmospheric moisture transport, which result in more Atlantic-sourced water precipitating over the Pacific (instead of back over the Atlantic), resulting in an increasing freshwater loss for the Atlantic Ocean.

Congo River Basin



From Washington et al., 2013

Congo River Basin



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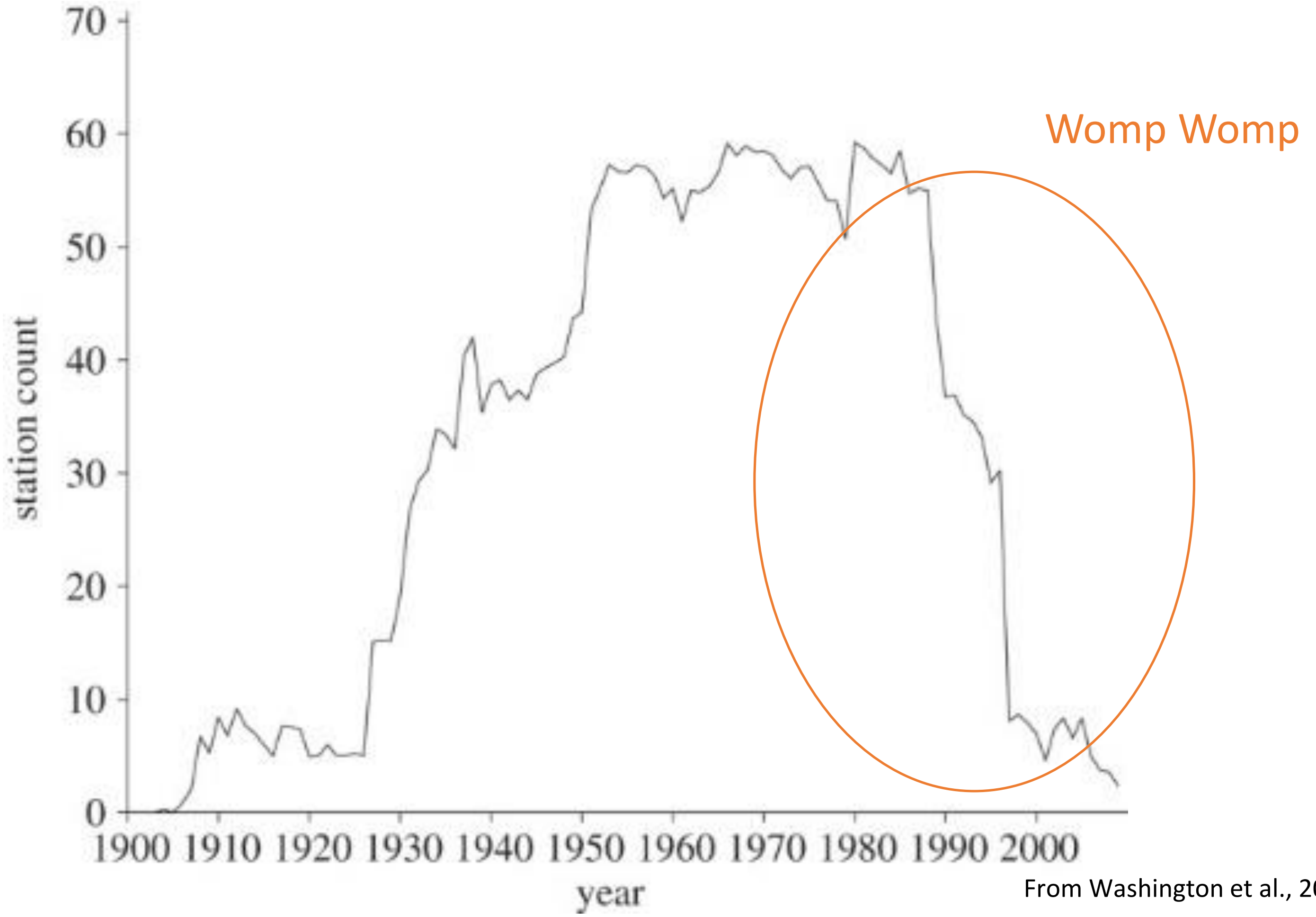

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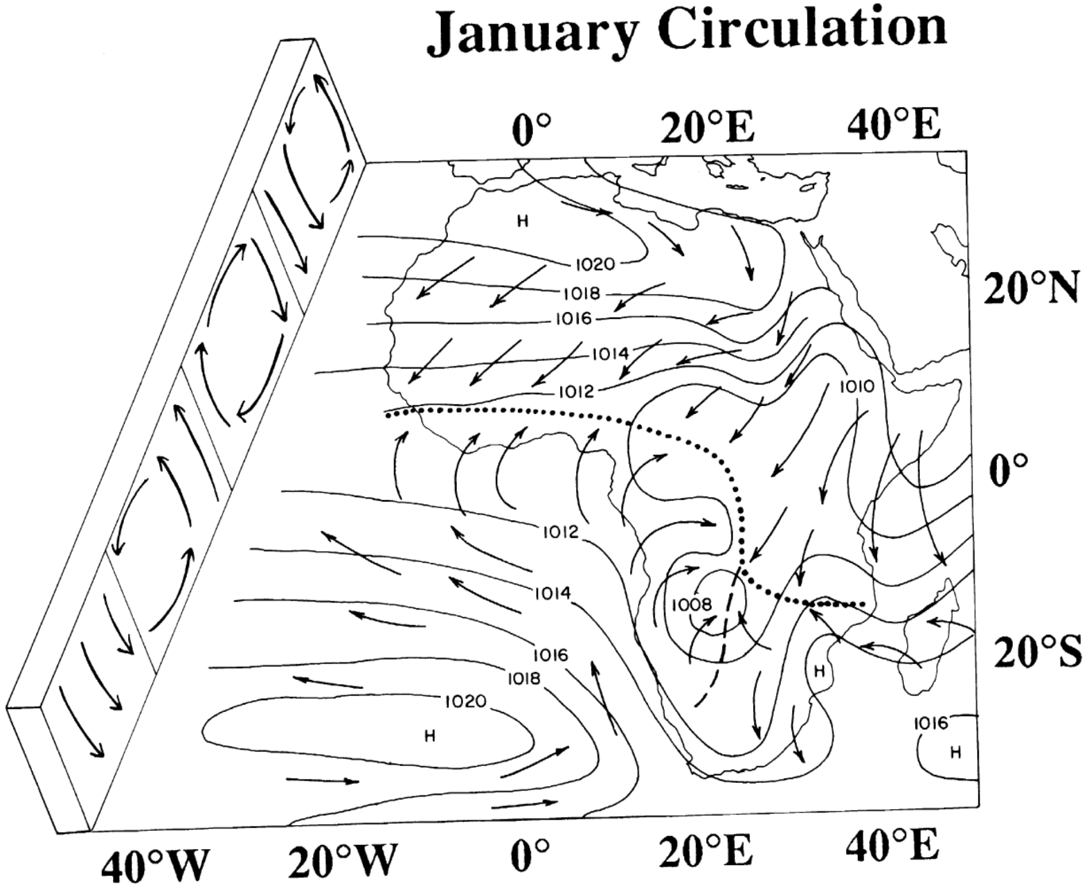
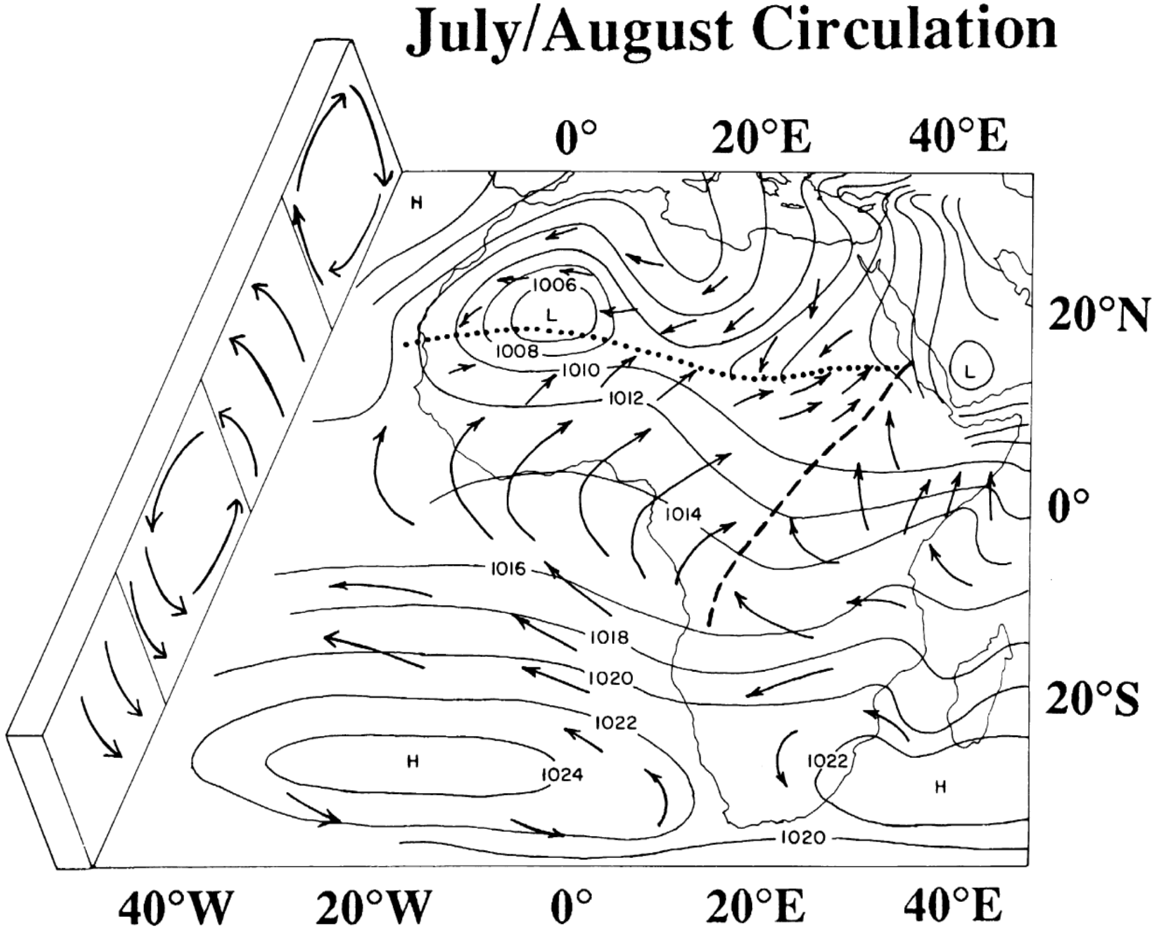
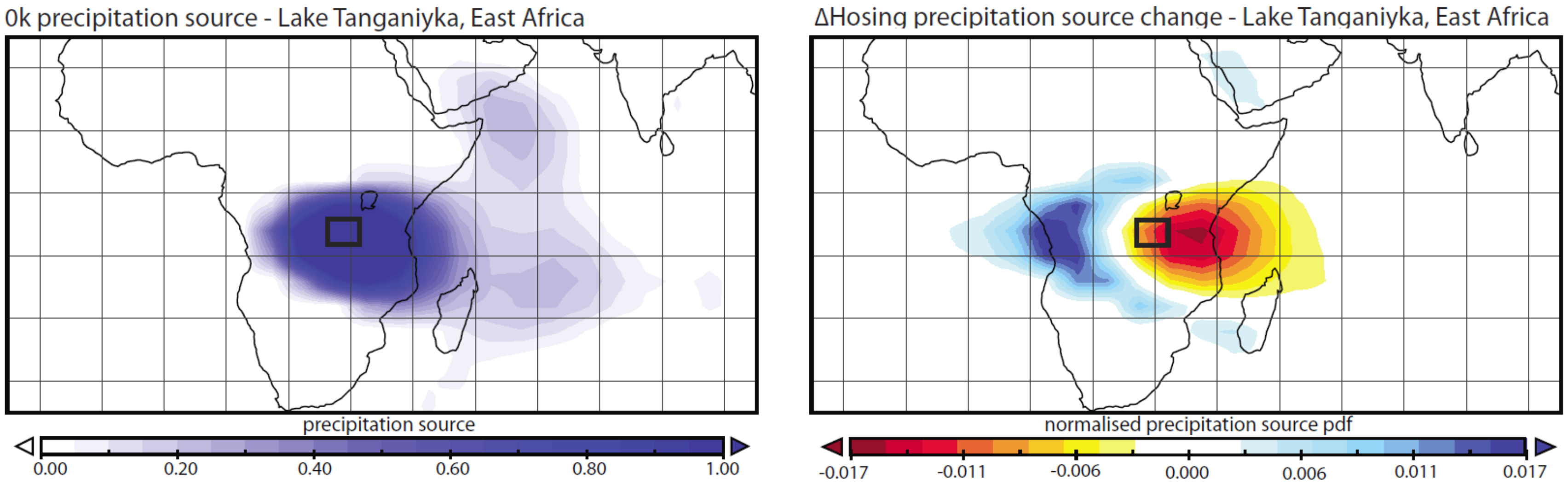




From Nicholoson, 2000

Precipitation source changes



From Lewis et al., 2010

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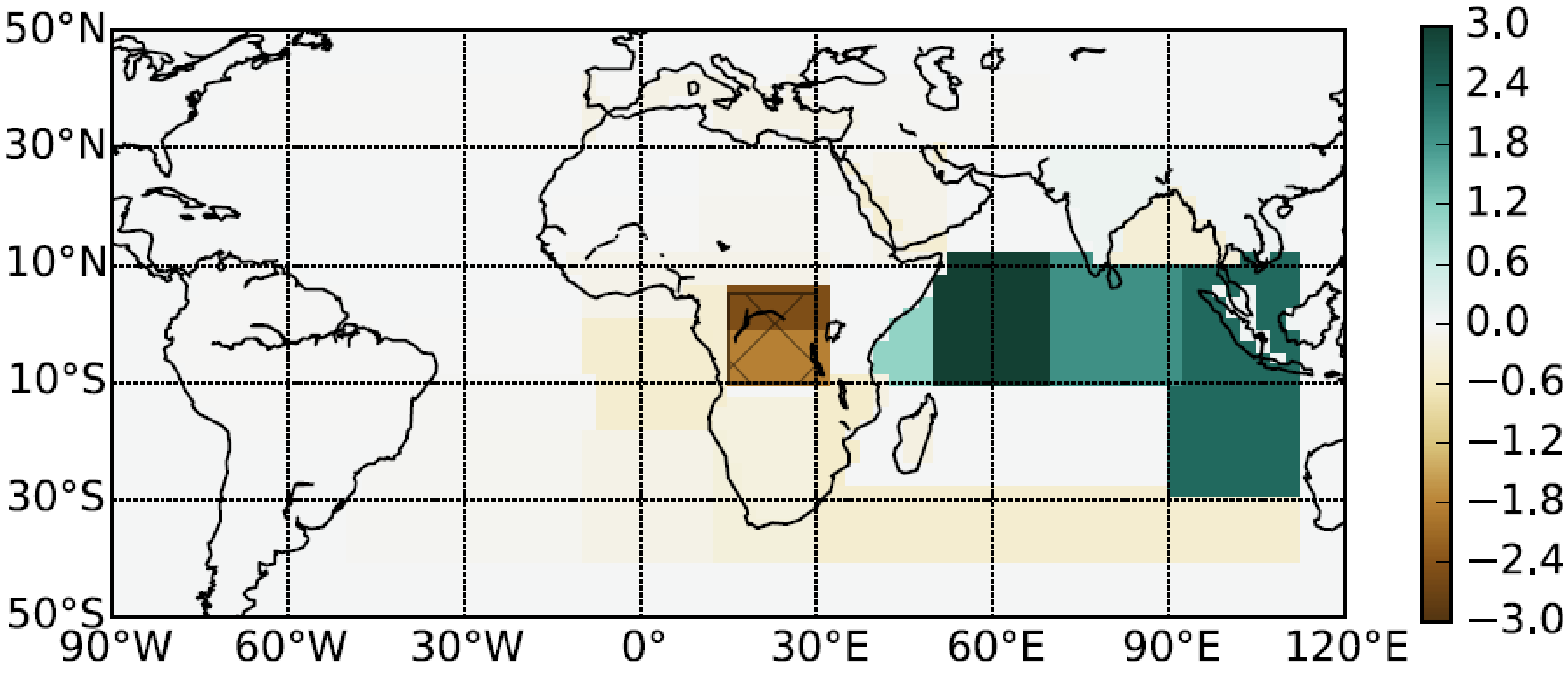
Congo River Basin

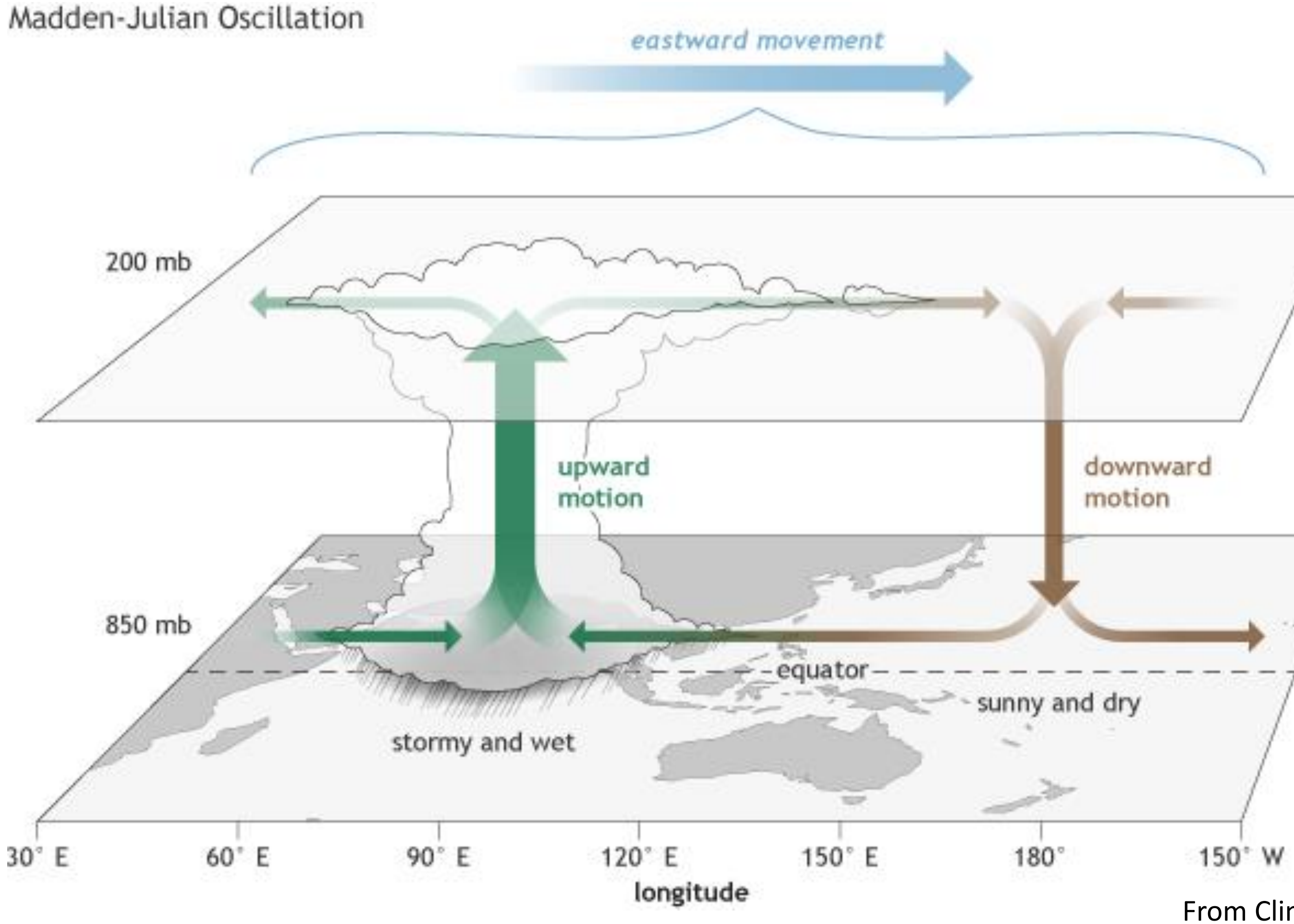


(a) *MAM*

From Dyer et al., 2017

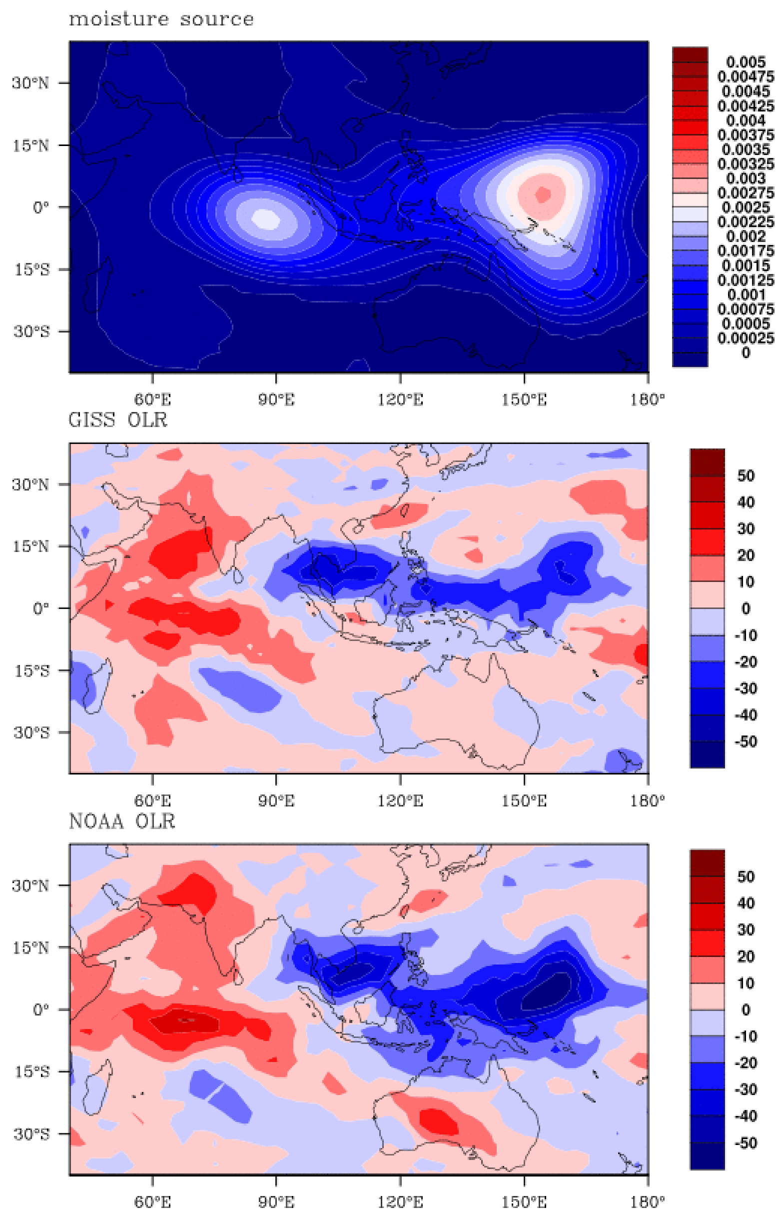
It has also been found that the inter-annual variability in Congo Basin precipitation is correlated to increases or decreases in Indian Ocean moisture, particularly from the Eastern Indian ocean.

The Madden-Julian Oscillation



From Climate.gov

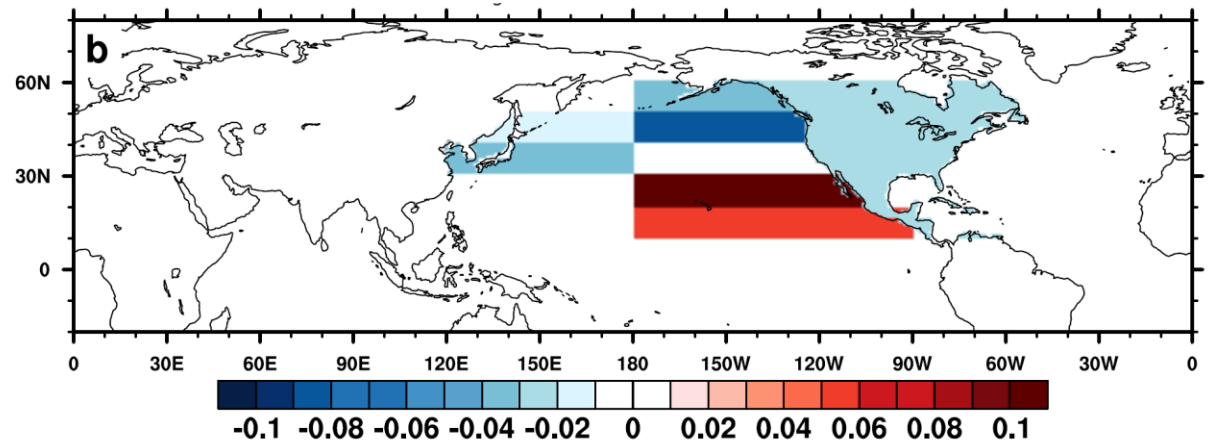
MJO Moisture Sources



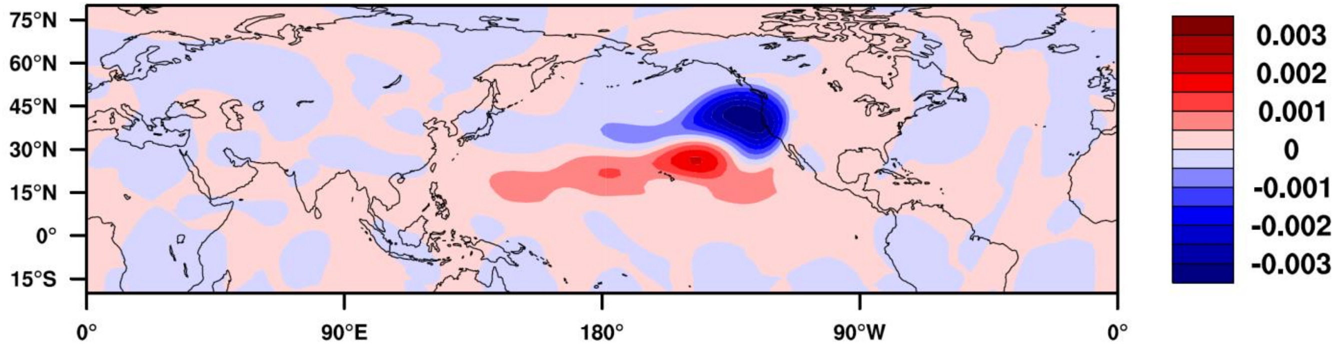
One Major Question

Can Water tracer simulations be validated using observations ?

GISS vs CAM5



NCAR CAM5

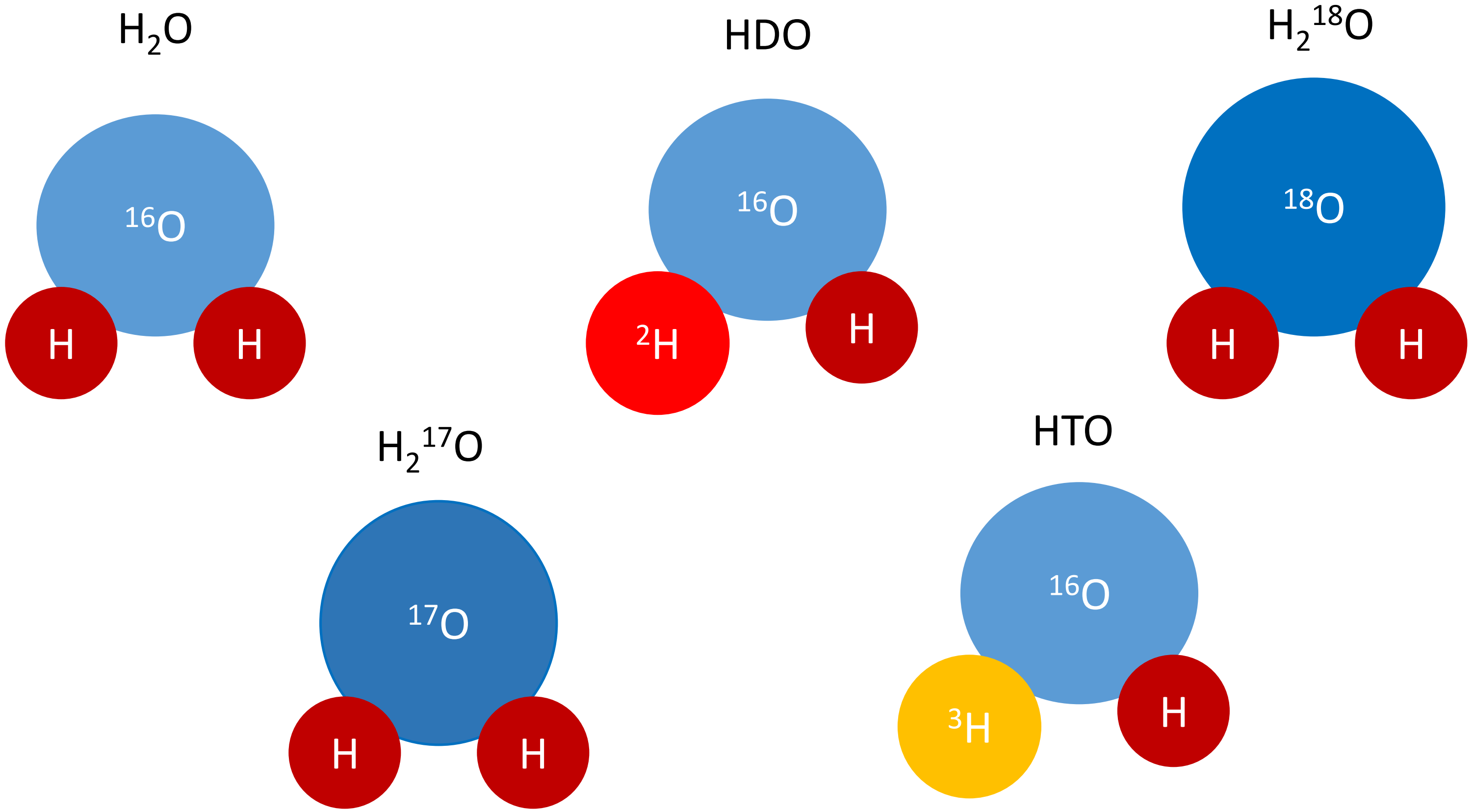


GISS ModelE2

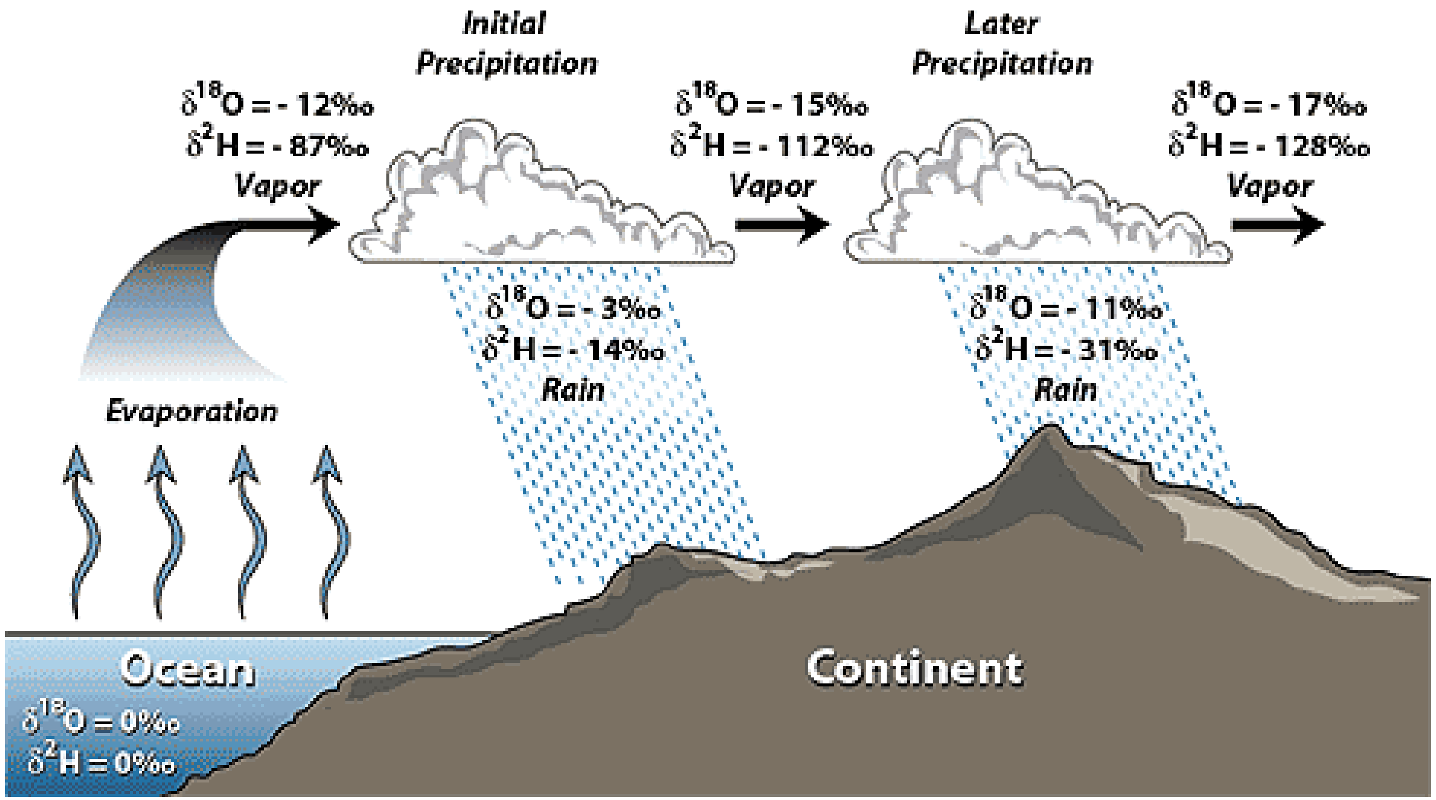
The GISS model contains a Tropical West Pacific change that's not present in CAM5. This could indicate a problem with atmospheric moisture transport in one of the models. Is there any way to determine which model is more accurate?

Water Isotopes

Water isotopes are informal jargon for “water isotopologues”, which are molecules of water with a heavy hydrogen or oxygen isotope.



Water isotopes

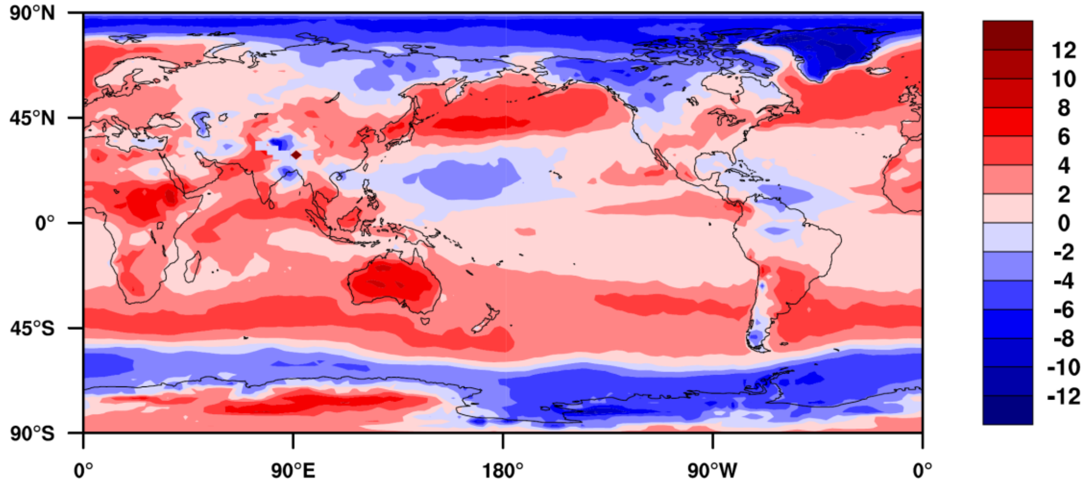


From sahra.arizona.edu

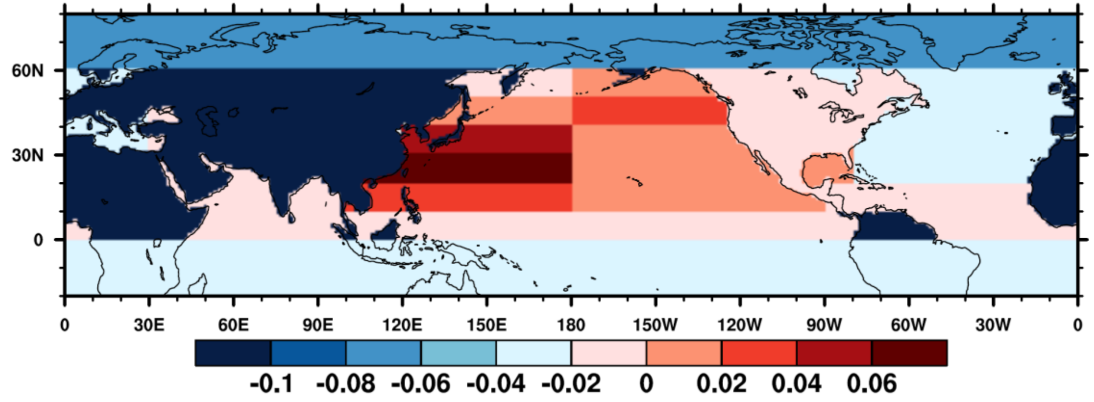
Differences in simulated water isotope values at any location is influenced by the model's representation of surface evaporation/transpiration, the boundary layer, atmospheric convection, and cloud physics.

Moisture source differences -JJA

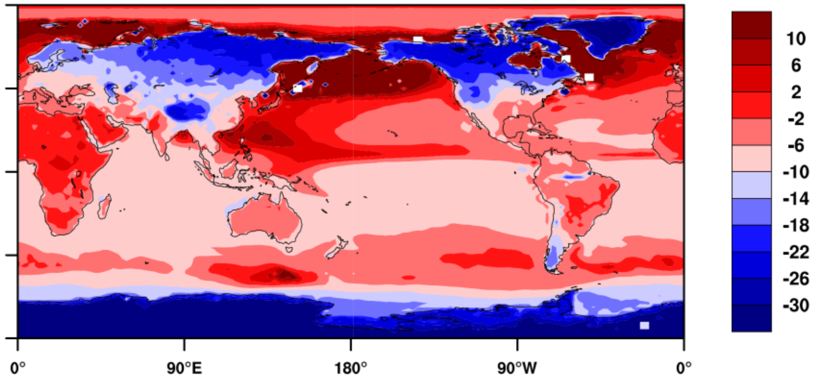
GISS-iCAM5: δ[18]Op (‰)



GISS-iCAM5: Moisture source fraction (unitless)

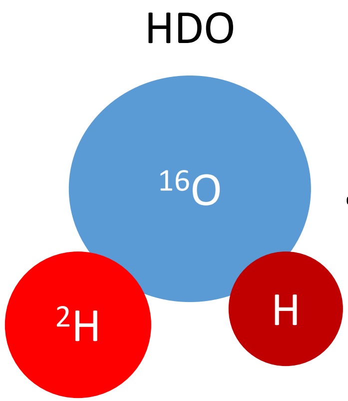


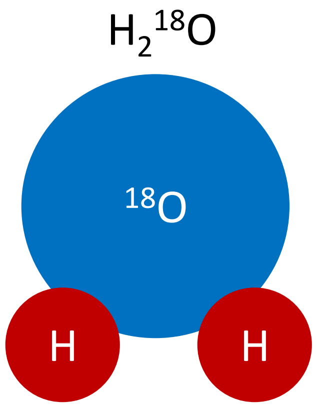
GISS δ[18]O of evaporation (‰)



This corresponds to more moisture from locations with enriched evaporation, producing enrichment in the storm track.

d-excess

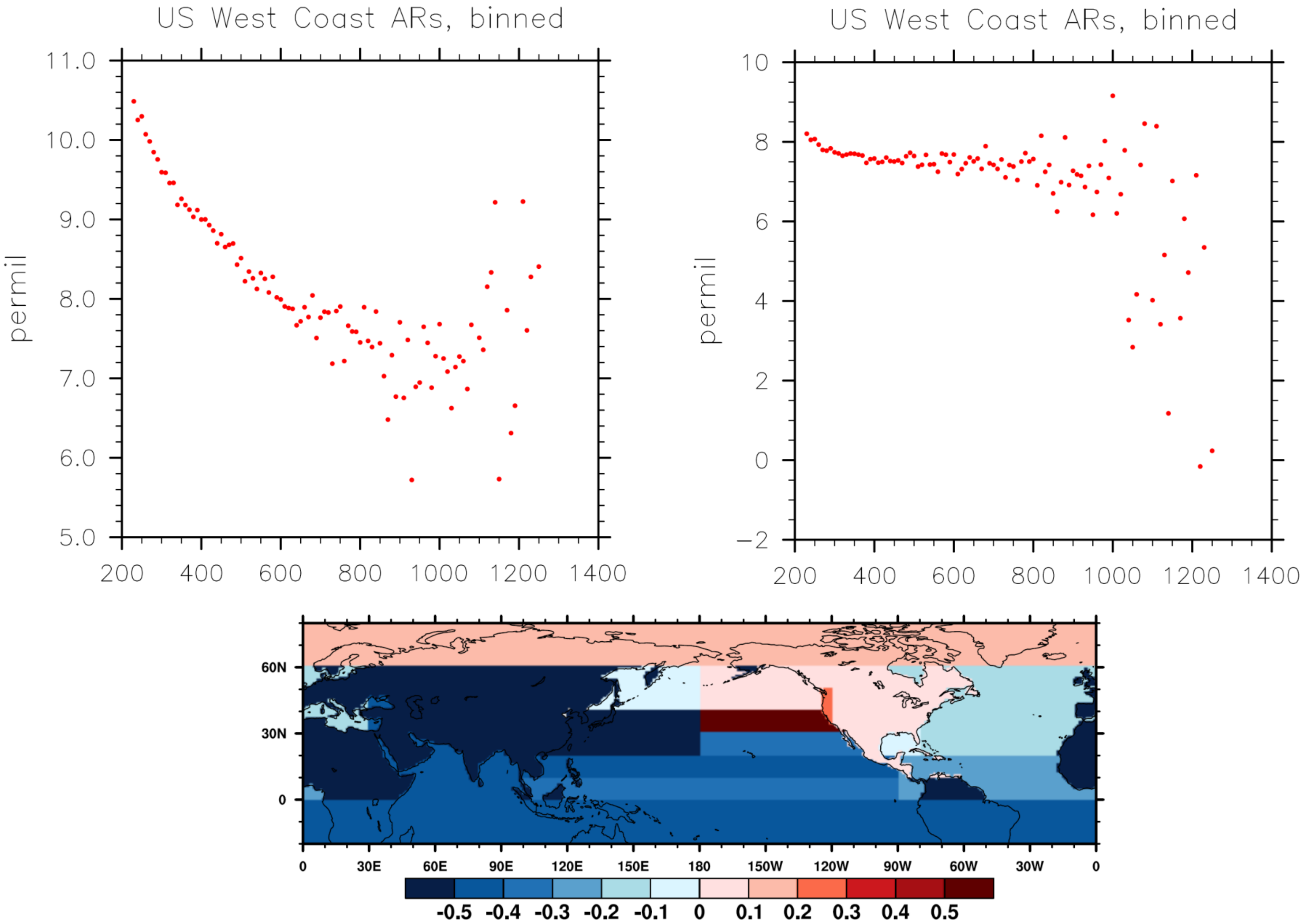
- d-excess = 

- 8* 

- This quantity is strongly dependent on the conditions during evaporation, but is insensitive to many atmospheric processes

- A case study found that the d-excess, once set during evaporation, was conserved while the water during transport poleward in an atmospheric river, possibly allowing it to potentially be an actual source marker, at least for this one weather phenomenon.

d-excess


US West Coast ARs, binned
permil
11.0
10.0
9.0
8.0
7.0
6.0
5.0
200
400
600
800
1000
1200
1400
US West Coast ARs, binned
permil
10
8
6
4
2
0
−2
200
400
600
800
1000
1200
1400
60N
30N
0
0
30E
60E
90E
120E
150E
180
150W
120W
90W
60W
30W
0
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
0.5

Conclusions

- Numerical Water Tracers in climate and weather models provide a way to determine what the source(s) of atmospheric moisture is for any particular location or atmospheric process, and how that source or sources my vary.
- They have been an available tool since the 1980s, and have been useful in examining numerous different scientific questions.
- However, there is a need to find observations capable of validating the tracer results, otherwise one may unable to reduce the uncertainty in moisture source projections between different climate models
- Water isotopes, and in particular d-excess, may hold the key to providing this constraint, at least for atmospheric rivers and/or the storm track regions.

Thanks for listening!

Questions?

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